NASA Contractor Report 159115

NASA-CR-159115
19820009645

DESIGN, FABRICATION AND TEST OF GRAPHITE/POLYIMIDE COMPOSITE JOINTS AND ATTACHMENTS FOR ADVANCED AEROSPACE VEHICLES

Quarterly Technical Progress Report No. 8

BOEING AEROSPACE COMPANY
Seattle, Washington 98124

NASA Contract NAS1-15644
July 1981

NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

FOREWORD

This report summarizes the work performed by the Boeing Aerospace Company (BAC) under NASA Contract NAS1-15644 during the period April 1, 1981, through June 30, 1981.

This program is sponsored by the National Aeronautics and Space Administration, Langley Research Center (NASA/LaRC), Hampton, Virginia. Dr. Paul A. Cooper is the Technical Representative for NASA/LaRC.

Performance of this contract is by Engineering Technology personnel of BAC. Mr. J. E. Harrison is the program Manager and Mr. D. E. Skoumal is the Technical Leader.

The following Boeing personnel were principal contributors to the program during this reporting period: J. B. Cushman, Design and Analysis; S. G. Hill, Materials and Processes.

TABLE OF CONTENTS

SUMMARY

This document reports on activities from April 1, 1981, through June 30, 1981, of an experimental program to develop several types of graphite/polyimide (GR/PI) bonded and bolted joints. The program consists of two concurrent tasks. TASK 1 is concerned with design and test of specific built-up attachments, while TASK 2 evaluates standard and advanced bonded joint concepts. The purpose is to develop a data base for the design and analysis of advanced composite joints for use at elevated temperatures (561K (550^{o}F)). The objectives are to identify and evaluate design concepts for specific joining applications and to identify the fundamental parameters controlling the static strength characteristics of such joints. The results from these tasks will provide the data necessary to design and build GR/PI lightly loaded flight components for advanced space transportation systems and high speed aircraft.

During this reporting period, principal program activities dealt with the literature survey, design allowables testing, preliminary evaluation of attachment concepts and final joint designs for scale-up verification fabrication and testing. Test results are presented for compression and interlaminar shear strengths of Celion 6000/PMR-15 laminates. Static discriminator test results for Type 3 and Type 4 bonded and bolted joints are presented and discussed. Final joint designs for TASK 1.4 scale-up fabrication and testing are also presented.

SECTION 1.0
INTRODUCTION

This is the 8th quarterly report covering results of activity during the period April 1, 1981, through June 30, 1981.

The purpose of this program is to provide a data base for the design of advanced composite joints useful for service at elevated temperatures (561K (550^{o}F)). The current epoxy-matrix composite technology in joint and attachment design will be extended to include polyimide-matrix composites. This will provide data necessary to build graphite/polyimide (GR/PI) lightly loaded flight components for advanced space transportation systems and high speed aircraft. The objectives of this contract are twofold: first, to identify and evaluate design concepts for specific jointing applications of built-up attachments which could be used at rib-skin and spar-skin interfaces; second, to explore advanced concepts for joining simple composite-composite and composite-metallic structural elements, identify the fundamental parameters controlling the static strength characteristics of such joints, and compile data for design, manufacture, and test of efficient structural joints using the GR/PI material system.

The major technical activities follow two paths concurrently. The TASK 1 effort is concerned with design and test of specific built-up attachments while the TASK 2 work evaluates standard and advanced bonded joint concepts.

The generic joint concepts to be developed under TASK 1 are shown in Figure 1-1. The total program scheduled is shown in Figure 1-2.

In TASK 1.1, several concepts were designed and analyzed for each bonded and each bolted attachment type and reported in Reference 1. Concurrent with this task a series of design allowable and small specimen tests were conducted under TASK 1.2. The analytical results of TASK 1.1 and the design data from TASK 1.2 were used to select the most promising bonded and bolted concepts.

In TASK 1.3, the most promising concepts for each joint type were fabricated and tested. Test results were used to define any design changes required for the preferred joint concepts. Final concepts will be evaluated based on weight

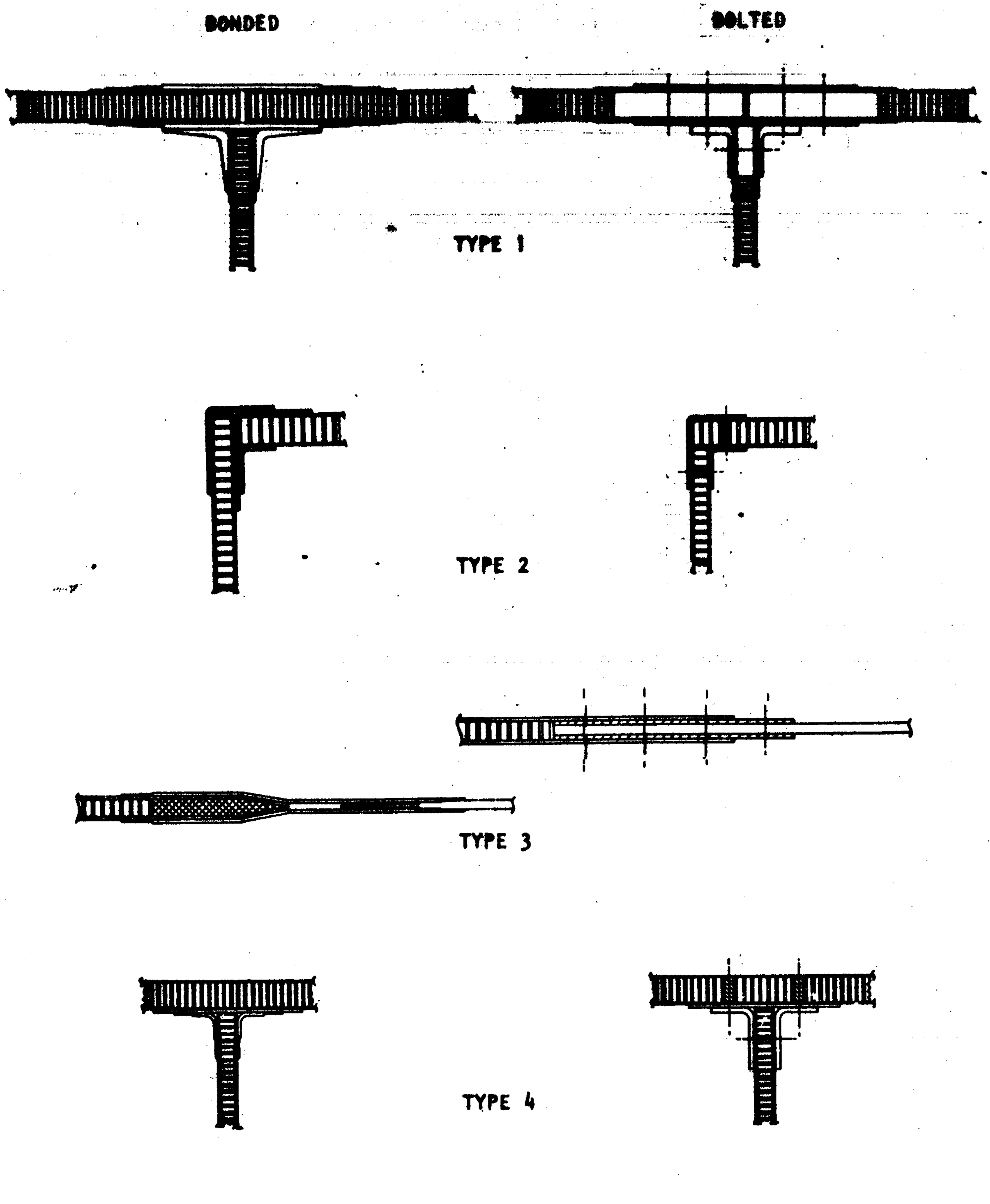
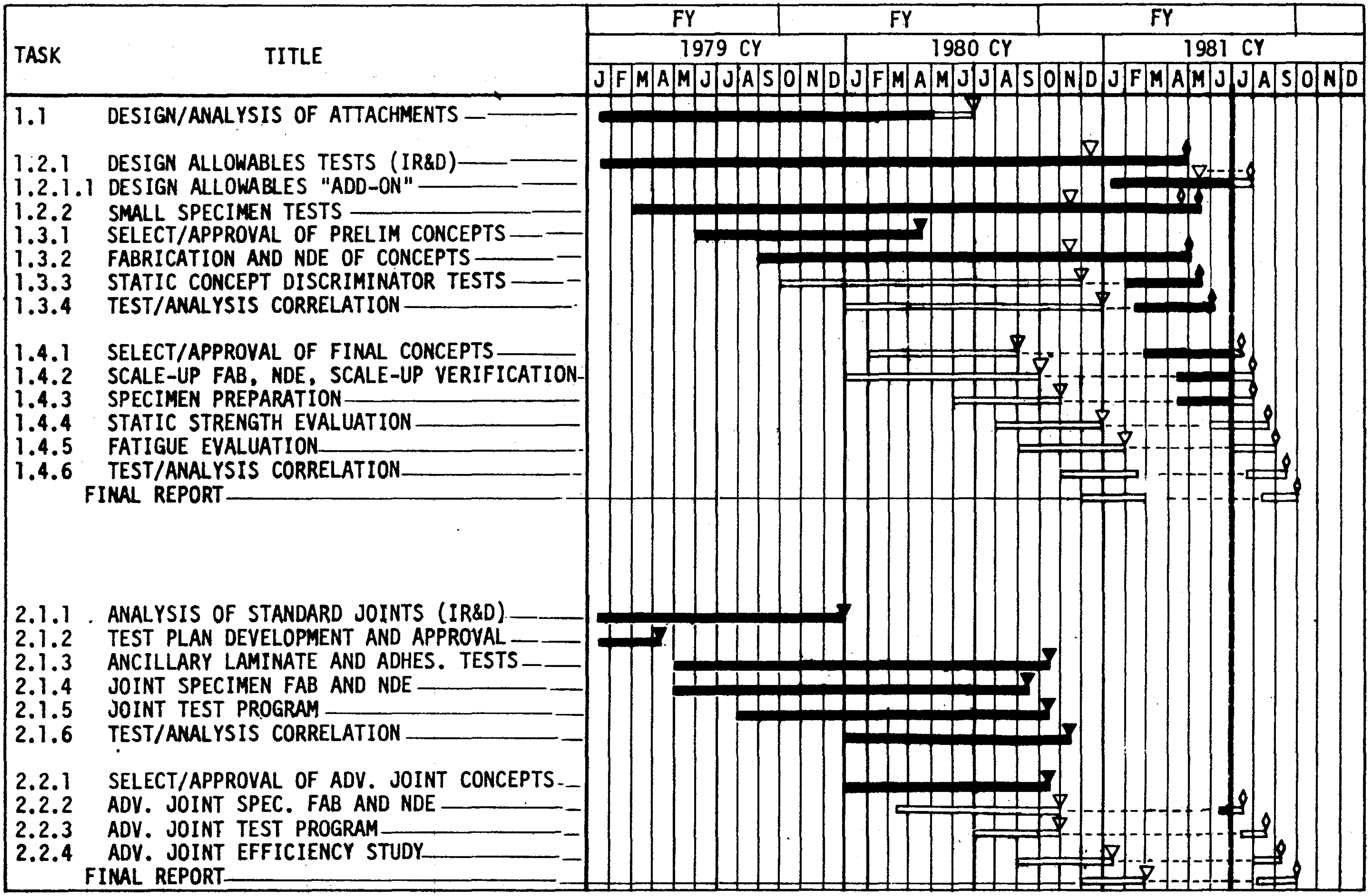


Figure 1-1: Generic Joint Concepts for 4 Attachment Types

NASA CONTRACT NAS1-15644

DESIGN, FABRICATION AND TEST OF GRAPHITE/POLYIMIDE COMPOSITE
JOINTS AND ATTACHMENTS FOR ADVANCED AEROSPACE VEHICLES



LEGEND

STATUS AS OF: 6-30-81

▼ ENDING DATE
◊ REVISED ENDING DATE

Figure 1-2: Master Program Schedule

efficiency, ease of fabrication, detail part count, inspectability and predicted fatigue behavior.

Finally, eight joint concepts (2 of each joint type) will be fabricated in TASK 1.4 on a scaled-up manufacturing basis to assure that reliable attachments can be fabricated for full-scale components. A series of static tests will be performed on specimens cut from the scaled-up attachments to verify the validity of the manufacturing process. Additional specimens will be thermally conditioned and tested in a series of static and fatigue tests. Test results will be compared with the analytical predictions and will be used to refine the final attachment concepts and to define design/analysis procedures.

The TASK 2 activity will establish a limited data base that will describe the influence of variations in basic design parameters on the static strength and failure modes of GR/PI bonded composite joints over a 116K to 561K (-250°F to 550°F) temperature range. The primary objectives of this research are to provide data useful for evaluation of standard bonded joint concepts and design procedures, to provide the designer with increased confidence in the use of bonded high-performance composite structures at elevated temperature, and to evaluate possible modifications to the standard joint concepts for improved efficiency.

To accomplish these objectives, activity under TASK 2.1 has consisted of design, fabrication, and static tests of several classes of composite-to-composite and composite-to-metallic bonded joints including single-and-double-lap joints and step-lap joints. Test parameters included lap length, adherend stiffness and stacking sequence at room and elevated temperatures. Under TASK 2.2, advanced lap joint concepts have been selected which show promise of improving joint efficiency. Concepts selected are pre-formed adherends, hybrid systems, and lap edge scalloping. These concepts will be statically tested and the results compared with the results from the standard joint tests.

This report summarizes the literature survey, presents static discriminator test results and results of design allowables testing completed during this reporting period.

SECTION 2.0
TASK 1 ATTACHMENTS

2.1 TASK 1.1 - Design and Analysis of Attachments

This section discusses the results achieved during this reporting period on the literature survey and on design and analysis of attachments.

2.1.1 Literature Survey

A comprehensive literature search was initiated at the beginning of the program to compile applicable experimental data and analyses concerned with the processing control, properties, and fabrication of GR/PI composite materials. In addition, the search was focused on design/analysis and evaluation of test data of bonded and bolted composite attachments.

The search has revealed an extensive amount of basic research, both completed and on-going, concerning attachments of composite structural members. Results of the literature search have been reported in previous Quarterly Report numbers 1 through 7. Review of current literature is a continuous on-going process during performance of this contract. A summary of relevant literature reviewed during this reporting period is given below.

Reference 2 presents results of analyses and tests to define stresses and strains in a double-lap joint bonded with a linear viscoelastic adhesive. The joint is subjected to a quasi-static load. The viscoelastic stress analysis is performed using Schapery's Direct Method of transform inversion and the SAAS III finite element program. The theory of modeling viscoelastic materials with finite elements is presented. Analysis results are corroborated with photoelastic and photoviscoelastic analyses of four double lap joint geometries.

Results of a parametric study of double-lap joints bonded with a viscoelastic adhesive are presented in Reference 3. The study is based on the analysis procedure presented in Reference 2 and quantitatively defines various material and geometric parameters needed to design an efficient joint. The most important parameter is the ratio of adherend modulus, E_M, to apparent adhesive modulus,

E_A. A dimensionless overlap ratio for adherends of identical materials is suggested that can be used to estimate joint efficiencies and where the adhesive peel and shear stresses will have the largest magnitude.

Reference 4 presents thermophysical properties data for HTS/NR150B2 and HTS/PMR-15 laminates over the temperature range of 116 K to 589 K (-250°F to 600°F). Data presented are thermal conductivity, thermal expansion, specific heat and emittance.

2.1.2 Design and Analysis

The design analysis procedure used to develop the joint designs is shown in Figure 2-1 which illustrates the interaction between design, analysis and test. Shaded areas indicate percent completion.

Basic designs for all the bonded and bolted joints were presented in the 5th Quarterly Report (CR 159112). These designs along with small specimen test results were used to arrive at the static discriminator specimen configurations presented in the 6th Quarterly Report (CR 159113). Results of the static discriminator tests have been used to arrive at the final joint designs for scale-up fabrication and test under TASK 1.4. Detail drawings of the joint designs are presented and discussed in section 2.4.

2.2 TASK 1.2 - Material and Small Component Characterization

This section discusses design allowables and small specimen testing.

2.2.1 TASK 1.2.1.1 - Design Allowables Modification

IITRI compression tests of Celion 6000/PMR-15 laminates have been completed except for specimens with strain gages. Test results are presented in Figure 2-2 and compare favorably with results published in Reference 5 for HTS-1/PMR-15 laminates of similar lay-ups. Room temperature data are compared to results from sandwich beam tests and face supported "end loaded" coupon tests in Figure 2-3. The IITRI and "end loaded" coupon tests give higher failure stresses than the sandwich beam tests. Because of the simplicity of the

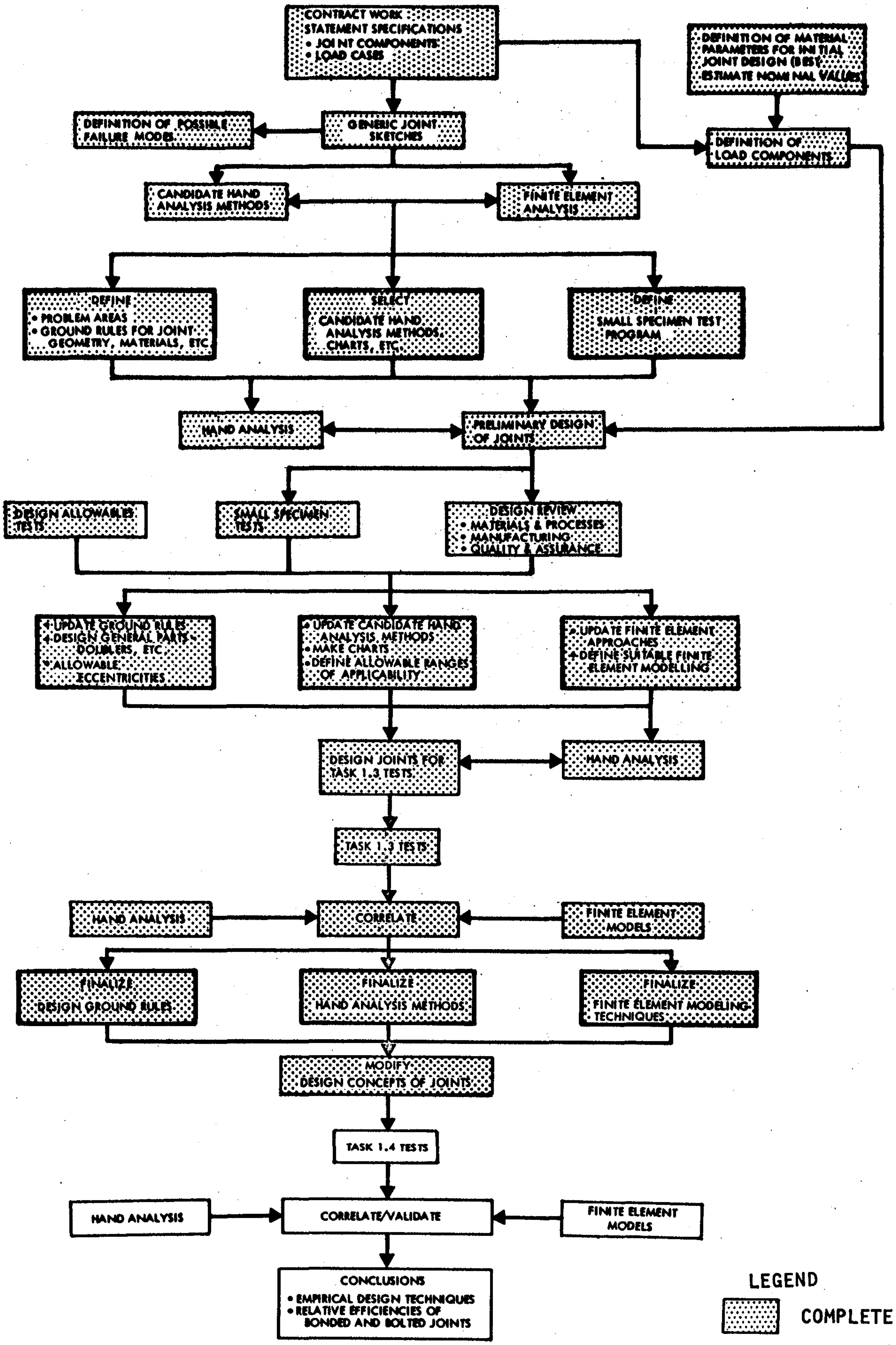


Figure 2-1: Task 1 Design/Analysis/Test Flow Diagram

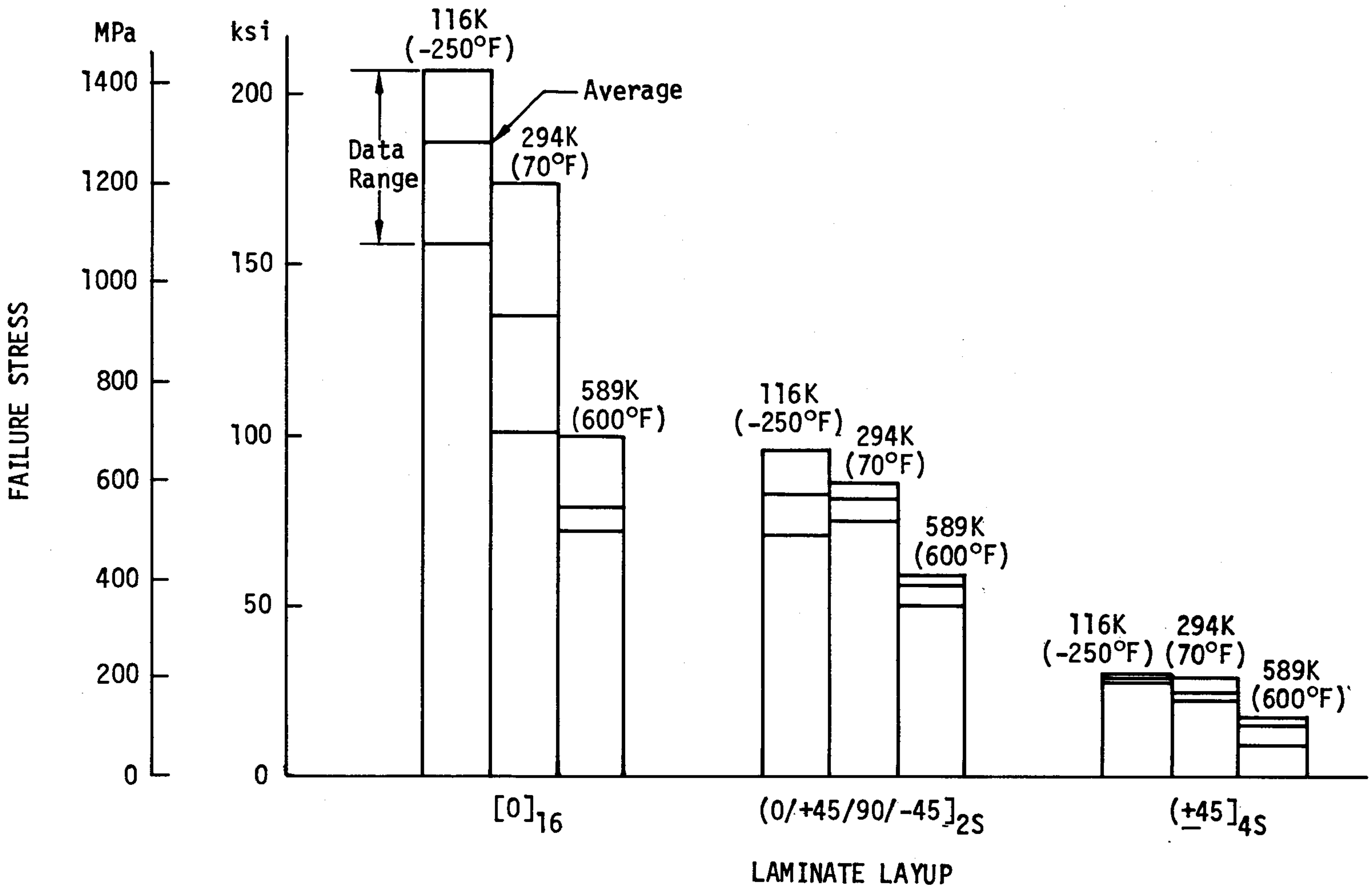


Figure 2-2: IITRI Compression Tests, Celion 6000/PMR-15, Baseline "Dry"

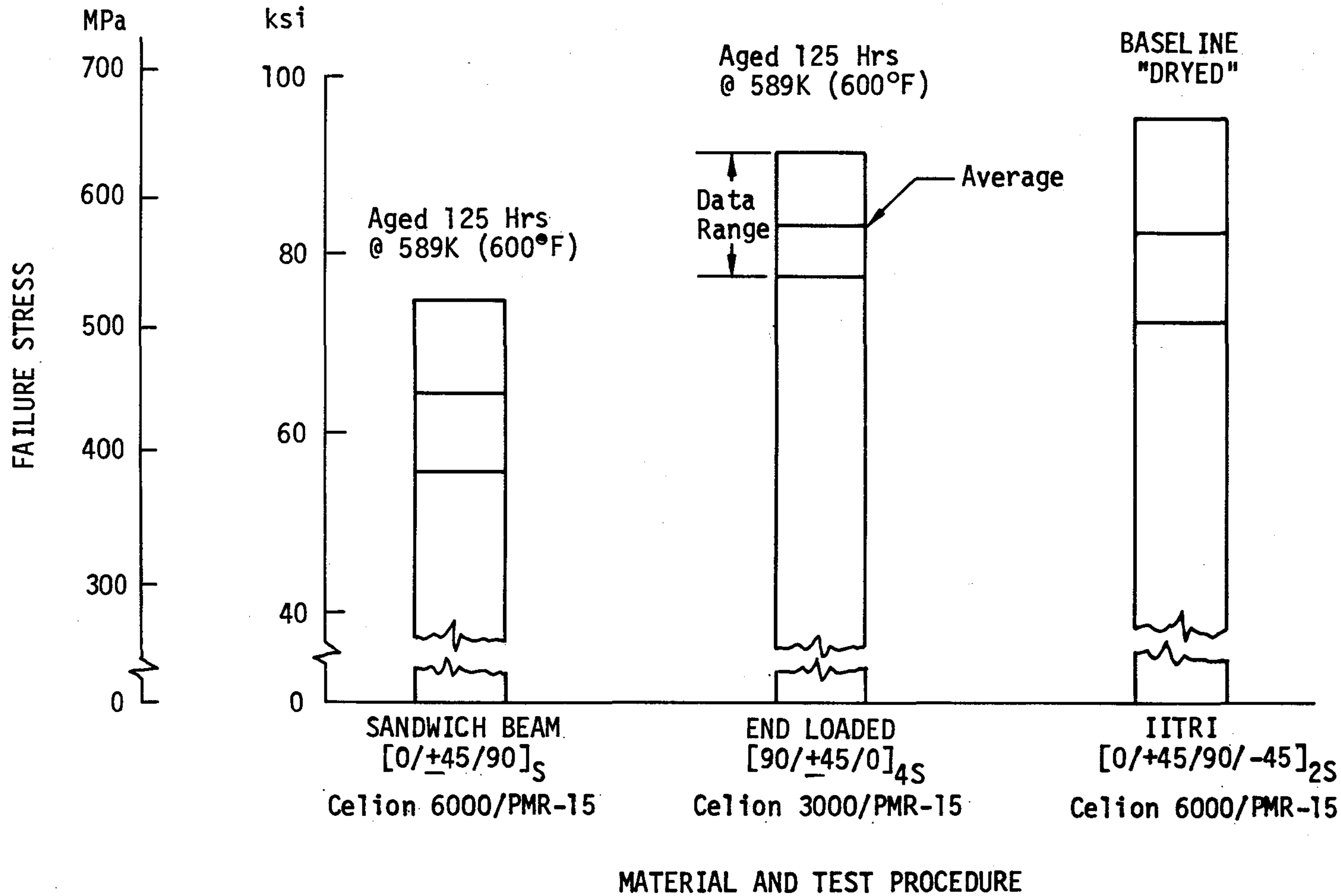


Figure 2-3: Comparison of Compression Test Results Room Temperature

"end loaded" coupon specimen and test fixture and the corresponding reduced cost, this test procedure should be considered for future testing. This is consistent with results and recommendations in Reference 5.

Results of short beam shear tests of Celion 6000/PMR-15 are given in Figure 2-4. All data exceed the minimum specification requirement as shown.

2.2.2 TASK 1.2.2 - Small Specimen Tests

Tests of 45.7mm (1.8 inch) double lap bonded joints of honeycomb sandwich (Matrix 4B test 4A) have been completed. All specimens failed in the laminate near the end of the load grip (hydraulic grips were used). Typical failed specimens are shown in Figure 2-5. Average failure loads at room temperature and 561 K (550^{0}F) were 10.7 kN (2400 lbs) and 10.2 kN (2295 lbs) respectively. These correspond to average laminate stresses of 409 MPa (59.3 ksi) and 388 MPa (56.3 ksi) which are approximately 73% of ultimate. Some of the specimens had signs of first ply damage in the bonded areas of the load tabs which would explain the low failure loads. These tests were originally intended to verify bonded lap lengths and doubler design for Type 1 joints prior to the static discriminator tests. However, because of late specimen delivery the static discriminator specimens were tested first and showed that the doubler design was not adequate. New interleaved doubler designs were tested and shown acceptable (see section 2.3.3); therefore, no retesting of Matrix 4B, test 4A is planned.

2.3 TASK 1.3 - Preliminary Evaluation of Attachment Concepts

This section discusses results of static discriminator tests of Type 3 and Type 4 bonded and bolted joints and of special interleaved doublers.

2.3.1 Type 3 Bonded and Bolted Joints

Tension tests of Type 3 bolted joints have been completed. Test specimens are shown in Figures 2-6 and 2-7. Each specimen tested had some delaminations present in the bolt area prior to test as shown in Figure 2-8; however, they

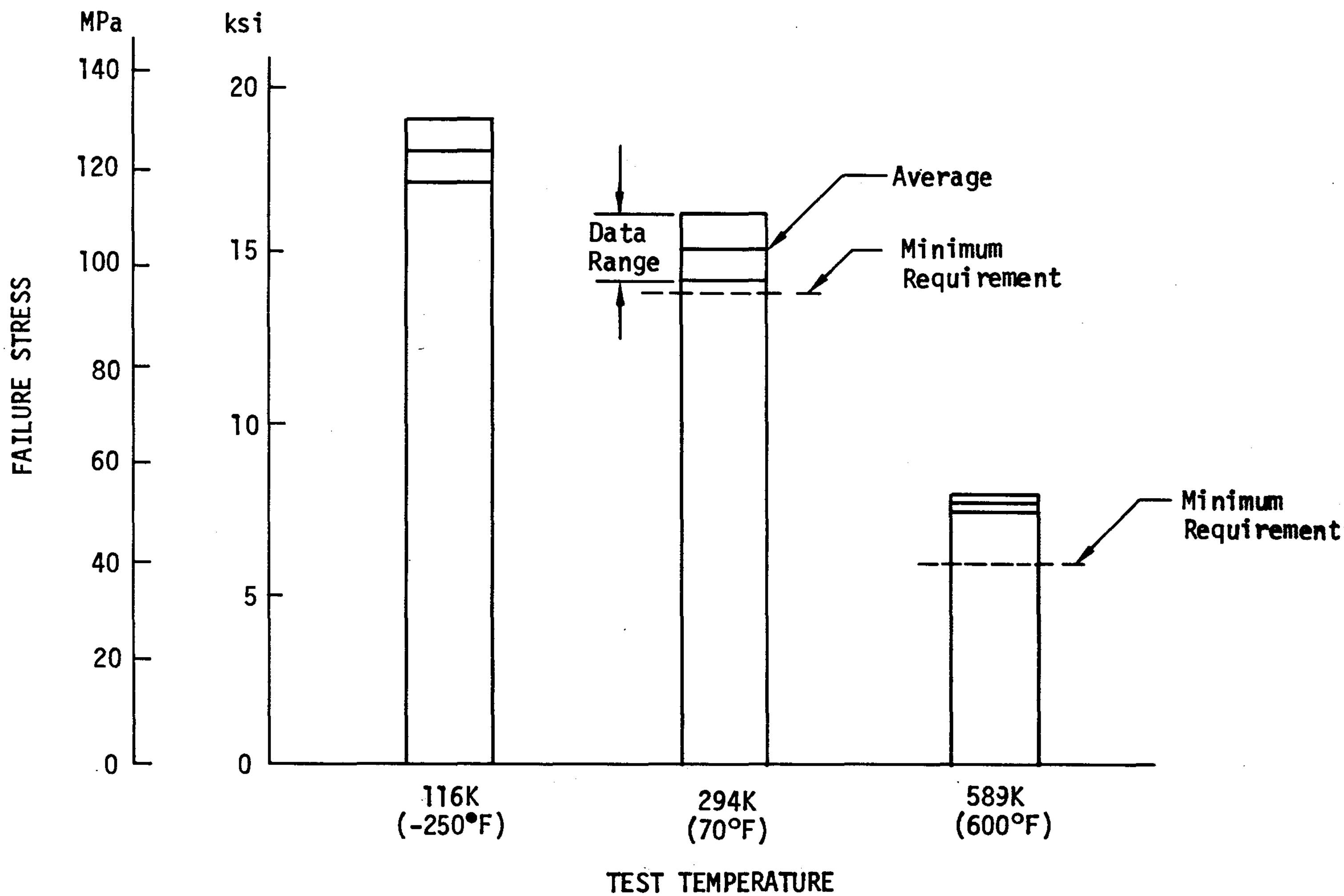


Figure 2-4: Short Beam Shear Tests Celion 6000/PMR-15 $[0]_{16}$ Baseline "Dry"

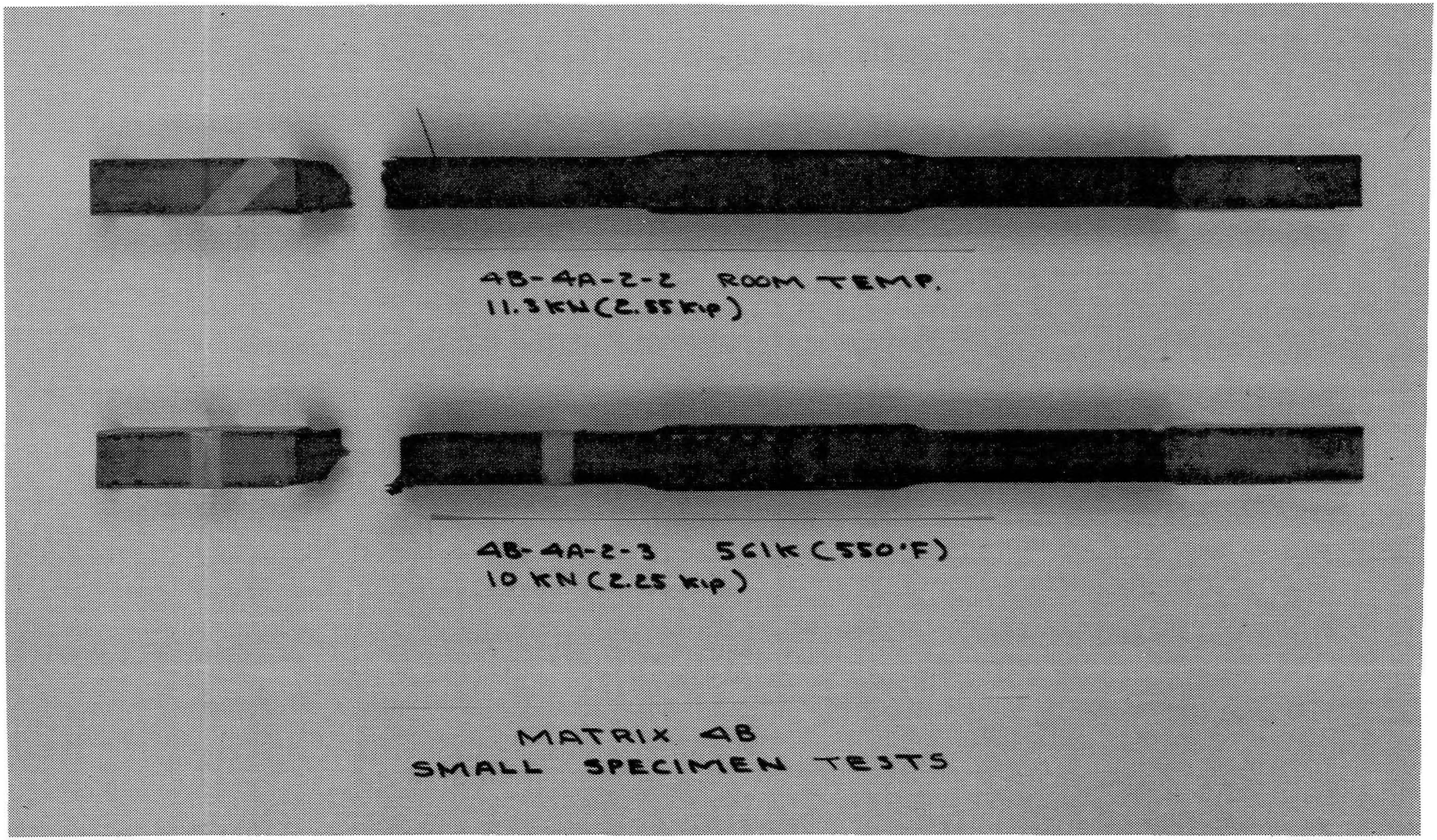


Figure 2-5: Small Speciman Tests - Matrix 4B Test 4A

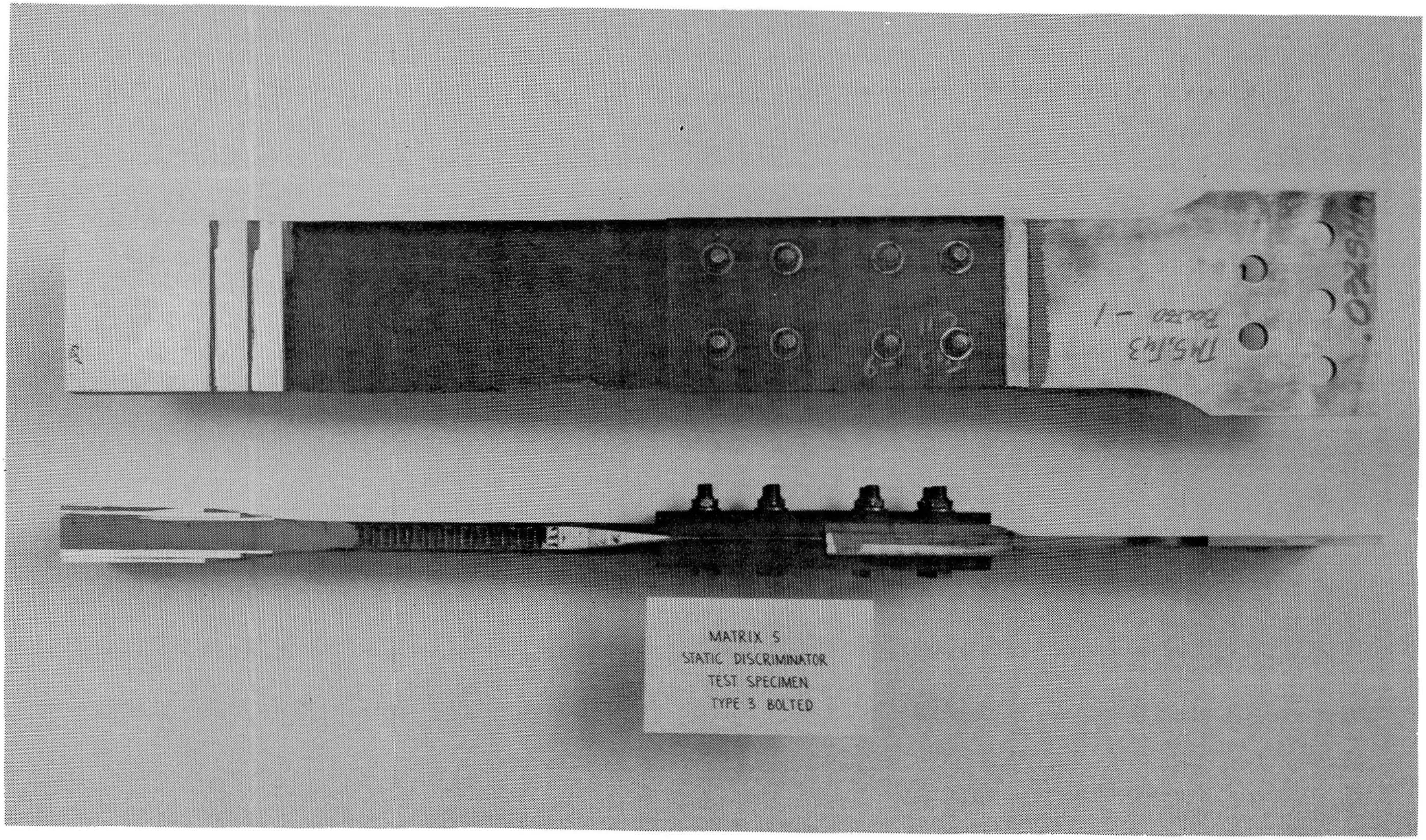


Figure 2-6: Static Discriminator Test Specimen Type 3 Bolted Gr/Pi Splice Plate

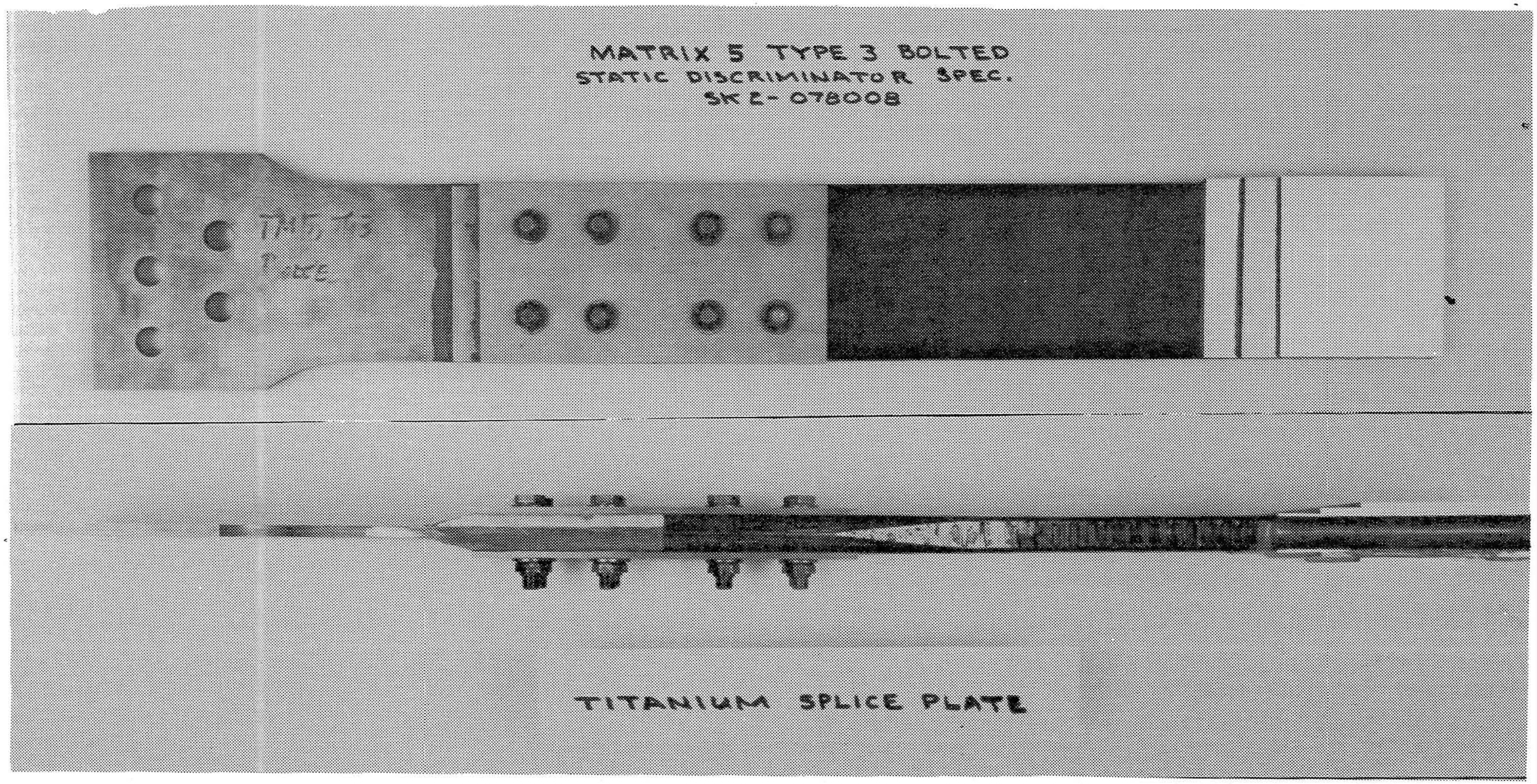


Figure 2-7: Static Discriminator Test Specimen Type 3 Bolted Titanium Splice Plate

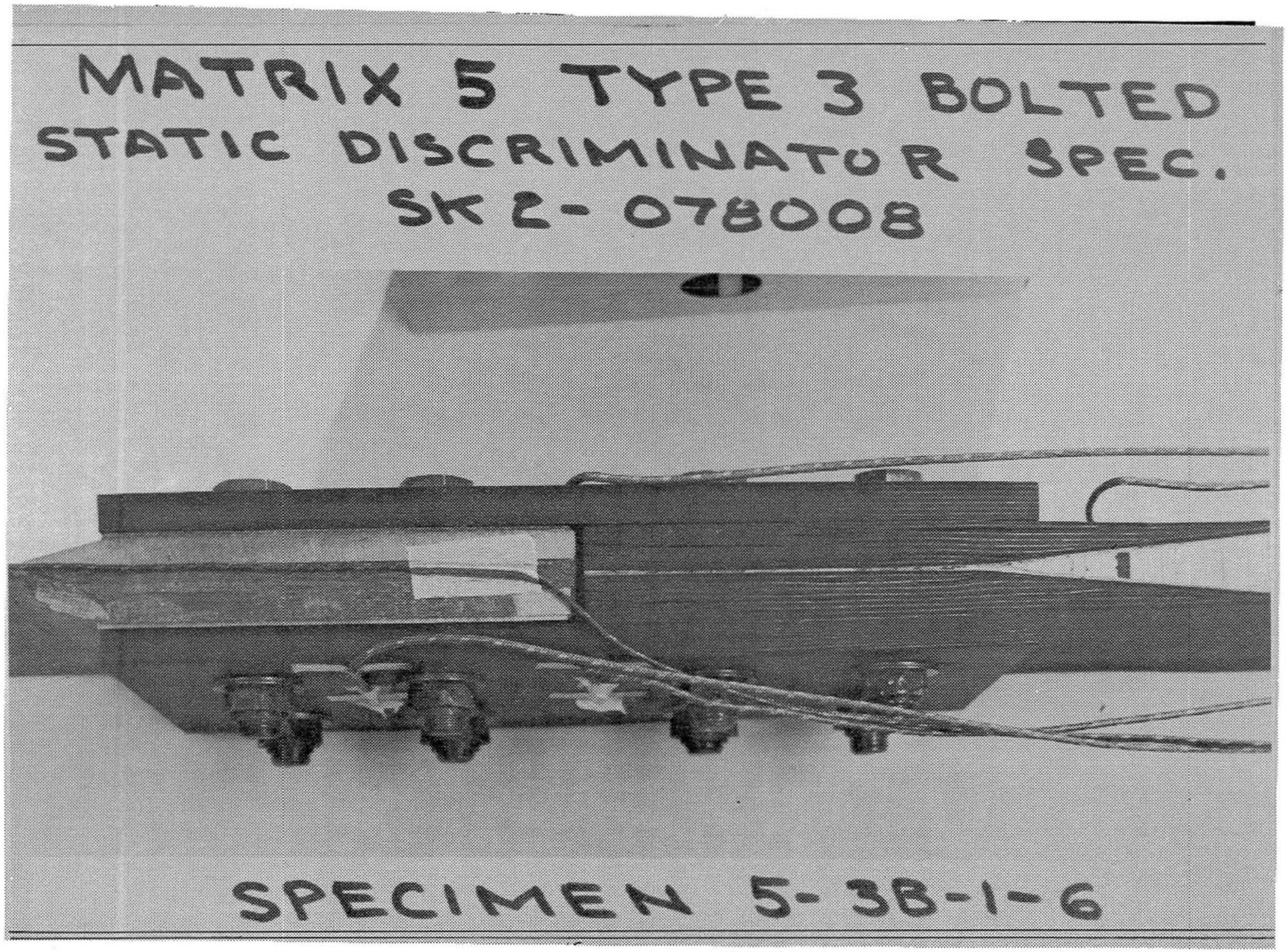


Figure 2-8: Type 3 Bolted Joint Pad-Up Delamination

did not affect the test results. Test results are summarized in Table 2-1 and are discussed below.

The joints were designed to carry a minimum load of 2.10 kN/mm (12,000 lbs/in); however, they must fail in the basic skin outside the joint area so that the joint is at least 100% efficient. Since the basic skins must be symmetric pseudo-isotropic lay-ups, the minimum gage that will meet the load requirement is 4.06 mm (0.16 in). This gage has a failure load of 2.24 kN/mm (12,800 lbs/in).

In all cases the specimens failed prematurely in the grip area. Typical failed specimens are shown in Figures 2-9 through 2-11. Failure loads varied from 75% to 92% of the design requirement (exclusive of specimen 5-3B-1-1 which had a bolted grip and failed at 62%). Post test examination of the specimens showed evidence of first ply damage in the load tab area. This probably occurred during preparation of the composite surface for bonding of the aluminum load tabs. In some cases the first ply had been sanded completely through exposing the second lamina. The titanium splice plate specimen (5-3B-1-7) had the least evidence of first ply damage and the highest failure load.

Another factor that may have contributed to the grip failure is having the aluminum load tabs bonded to a 0^{o} layer at the interface followed by a 90^{o} ply. Since the 90^{o} ply would carry very little shear, most of the shear load would be transferred into the first 0^{o} ply. This coupled with first ply damage discussed above would explain the premature failures.

It is planned to change the load grip design on Type 3 joints to be fabricated for TASK 1.4. Finite element analyses of a double lap bonded joint (see Ref. 1) has shown that putting $+45^{o}$ plies at the interface gives a more uniform shear distribution (i.e., lower peak shear stresses). Since the original Type 3 static discriminator specimens (TASK 1.3) were designed with a 3 bolt load grip, this was not considered important. Going to hydraulic load grips changed the load transfer mechanism. Specimens for TASK 1.4 will have a $\pm 45^{o}$ layer on the outer surface of the composite as well as an additional layer of GR/PI fabric in the grip area. This will give a softer shear transfer zone to minimize peak shear stresses. In addition, strict control will be

Table 2-1 Matrix 5 Static Discriminator Tests

Type 3 Bolted (SK2-078008)

Load Requirement 200 kN (45 kips)

SPECIMEN NO	TEMPERATURE K (°F)	FAILURE LOAD kN (kips)
5-3B-1-1 [1]	294 (70)	124 (27.9)
5-3B-1-2		173 (39.0)
5-3B-1-3		163 (36.6)
5-3B-1-7 [2]		184 (41.3)
5-3B-1-4	561 (550)	162 (36.5)
5-3B-1-5		165 (37.0)
5-3B-1-6		149 (33.6)

[1] This Specimen had a 3 Bolt Load Grip.
Specimen Failed in Net Tension in the Grip Area.

[2] This Specimen had Titanium Splice Plate

NOTE: All Specimens Failed in the Grip Area

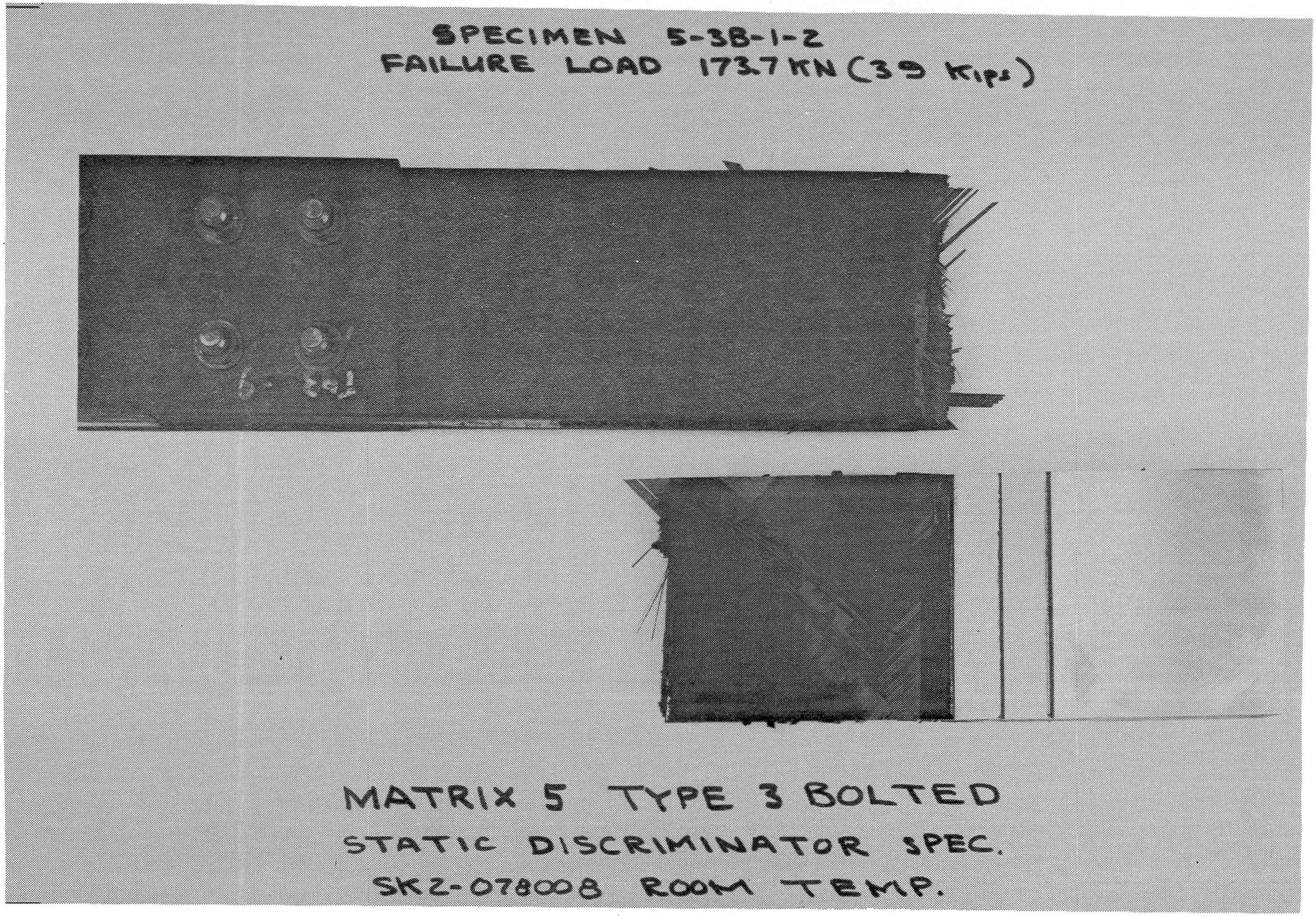


Figure 2-9: Static Discriminator Tests Type 3 Bolted Gr/Pi Splice Plate
Typical Failure - Room Temperature

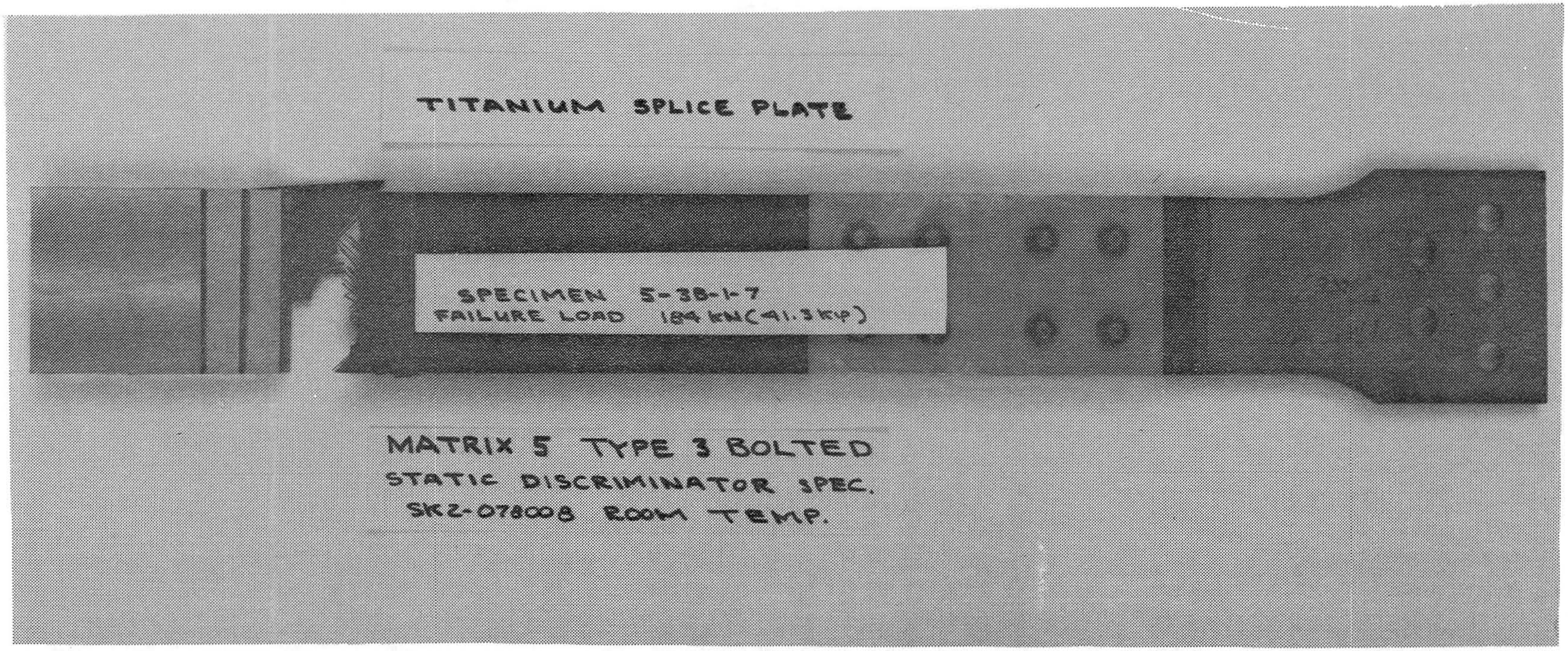


Figure 2-10: Static Discriminator Tests Type 3 Bolted Titanium Splice Plate
Typical Failure - Room Temperature

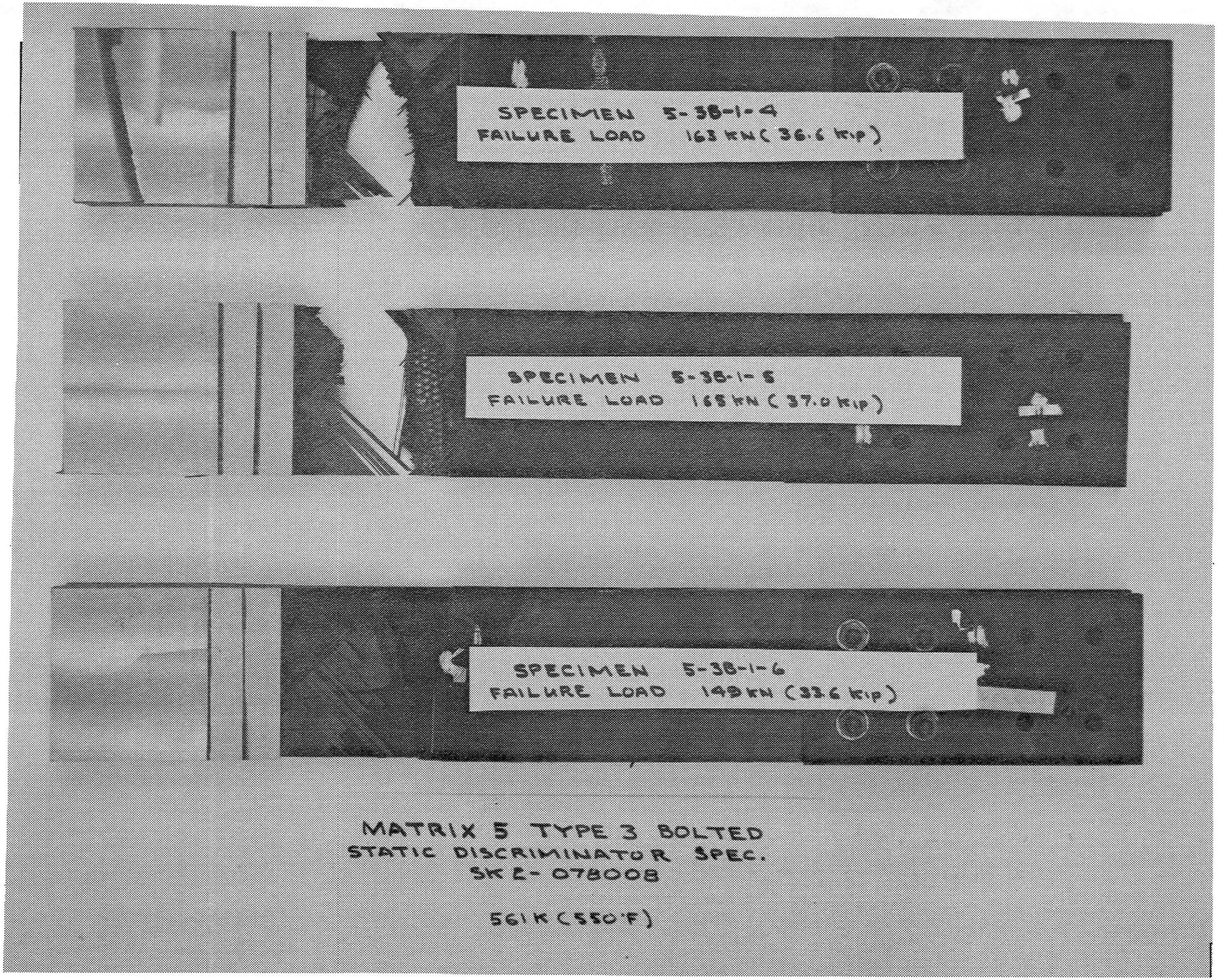


Figure 2-11: Static Discriminator Tests Type 3 Bolted Gr/Pi Splice Plate Failed Spec. 561K (550°F)

enforced in preparation of the composite surface for bonding to eliminate any first ply damage.

During the standard joint tests (matrix 3G) a 3.81mm (0.15 inch) thick 3 step symmetric step-lap joint of GR/PI to titanium was successfully co-cured and tested. Co-curing of a 6.35mm (.25 inch) thick 5 step joint, however, was unsuccessful. It was decided to use the static discriminator tests to conduct additional evaluation of possible co-curing processing techniques for the thicker step lap joints. A simple specimen configuration was chosen to minimize costs while demonstrating the adequacy of the co-curing processing. The first specimens were made by prestaging the adhesive primer to eliminate the adhesive volatiles prior to cocuring. C-scans of the cured specimens showed excessive bondline voids. The second specimens were processed by increasing the vacuum to bleed off the volatiles. These specimens also had excessive bond line voids visible as a large blister and also shown by the C-scans. These results show that adequate bonding procedures have not been developed for the thicker GR/PI to titanium step-lap joints.

As discussed above, attempts at cocuring symmetric step lap joints for a Type 3 bonded joint design have not been successful. Based on these results there will not be any scaling up of a Type 3 bonded joint for TASK 1.4. A co-cured bonded joint designed to carry 2.10 kN/mm (12 kips/in) is beyond the current "state-of-art" and would require additional development time and funding.

2.3.2 Type 4 Bonded and Bolted Joints

Testing of Type 4 bonded and bolted joints have also been completed. Typical joint configurations are shown in Figures 2-12 and 2-13. The specimens were loaded as shown in Figure 2-14. Test results are summarized in Tables 2-2 and 2-3.

All of the room temperature Type 4 bonded joints exceeded their minimum design requirement of 845 N (192 lbs). Two specimens failed in compression in the outer laminate of the cover outside the joint area. The other specimen failed at a higher load; however, it had an interlaminar tension failure of the

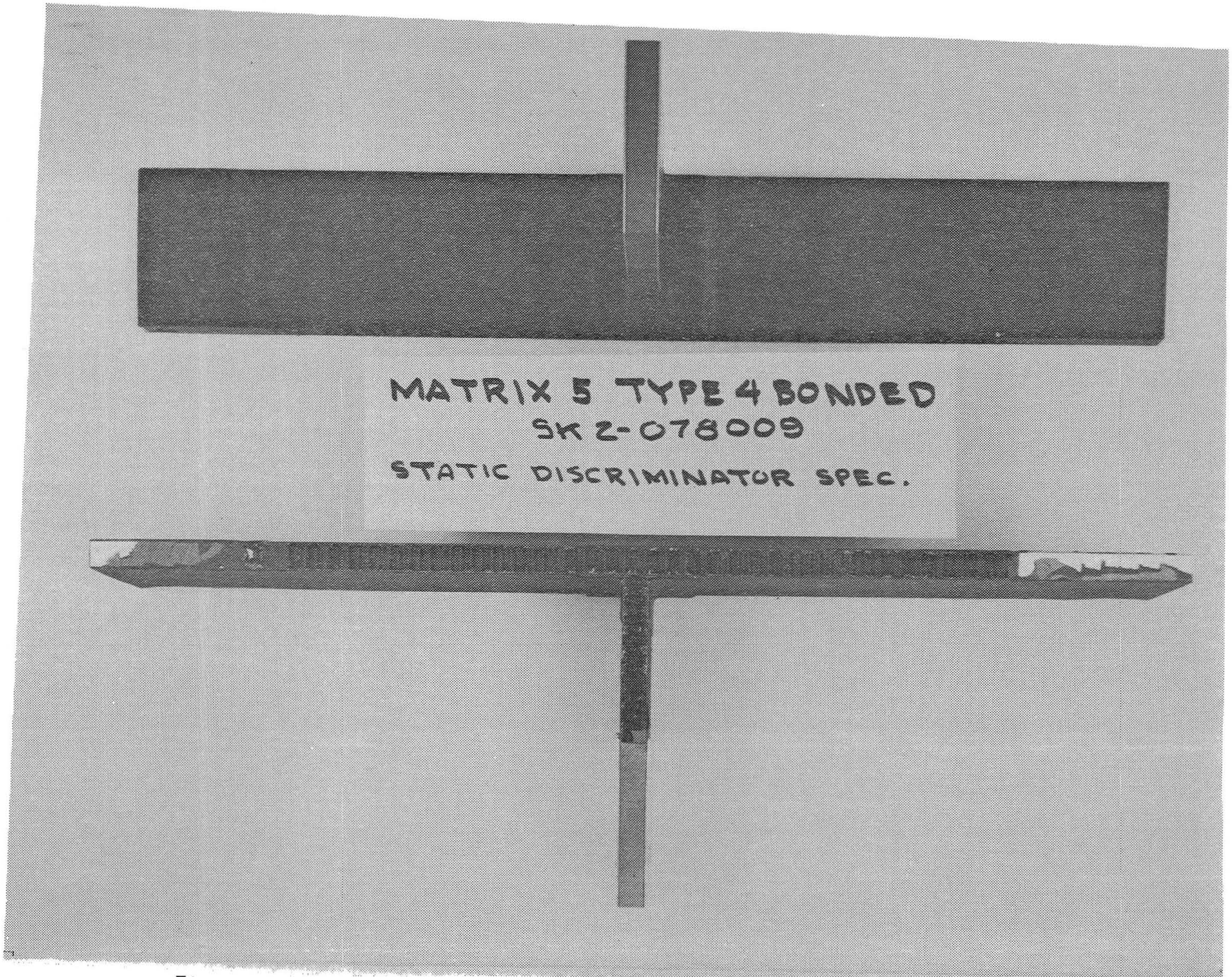


Figure 2-12: Static Discriminator Test Specimen Type 4 Bonded

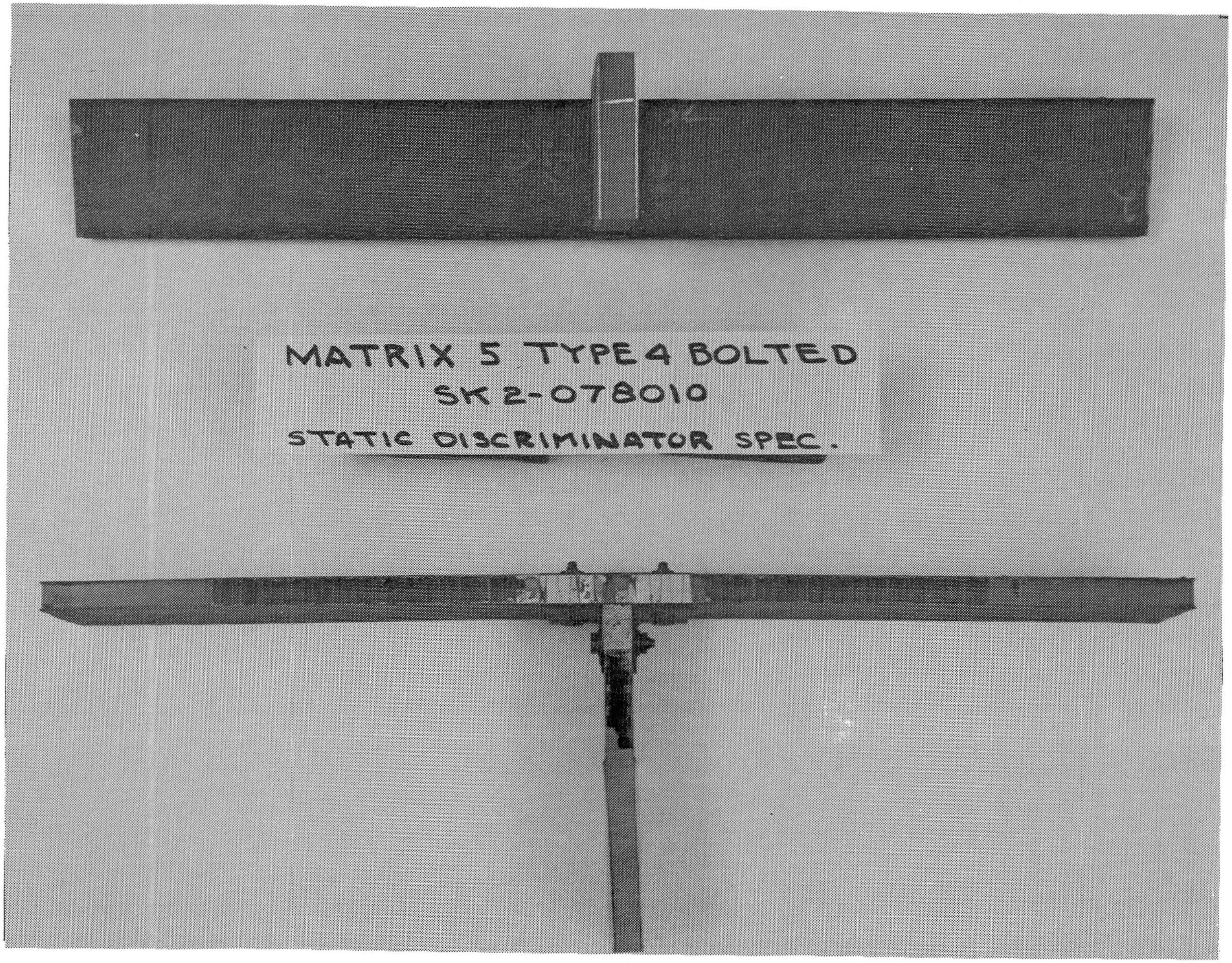


Figure 2-13: Static Discriminator Test Specimen Type 4 Bolted

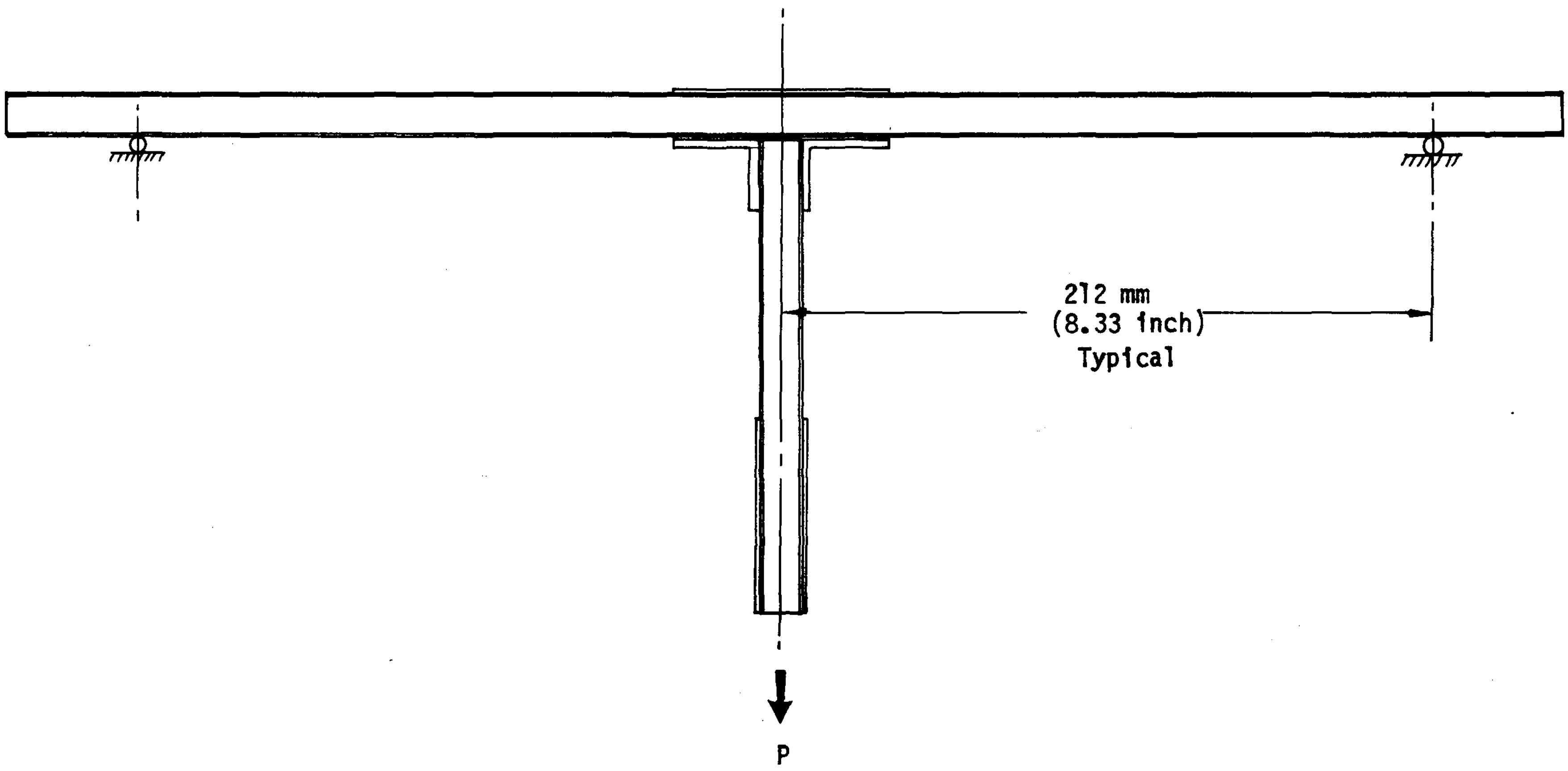


Figure 2-14: Typical Test Setup For Type 4 Bonded and Bolted Joints

Table 2-2 Type 4 Bonded Joints Matrix 5 Static Discriminator Tests
Load Requirement = 854 N (192 lbs)

SPECIMEN NO.	SPECIMEN WIDTH mm (in)	TEMPERATURE K (°F)	FAILURE LOAD N (lbs)	FAILURE MODE
5-4A-1-1	76.2 (3.0)	561 (550)	930 (209)	Attach Angle Pull-Off 1
5-4A-1-2	76.2 (3.0)	561 (550)	1072 (241)	Cover Laminate Compression
5-4A-1-3	76.2 (3.0)	561 (550)	792 (178)	Attach Angle Pull-Off 1
5-4A-1-4	76.2 (3.0)	294 (70)	1463 (329)	Cover Laminate Compression
5-4A-1-5	76.2 (3.0)	294 (70)	1455 (327)	Cover Laminate Compression
5-4A-1-6	76.2 (3.0)	294 (70)	1530 (344)	Attach Angle Pull-Off 2

1 Combined Cohesive and Interlaminar Tension on Attach Angle

2 Interlaminar Tension on Attach Angle

Table 2-3 Type 4 Bolted Joints Matrix 5 Static Discriminator Tests
Load Requirement = 712 N (160 lbs)

SPECIMEN NO.	SPECIMEN WIDTH mm (in)	TEMPERATURE K (°F)	FAILURE LOAD N (lbs)	FAILURE MODE
5-4B-1-1	63.5 (2.5)	561 (550)	1103 (248)	Cover Laminate Compression
5-4B-1-2	63.5 (2.5)	561 (550)	770 (173)	Cover Laminate Compression
5-4B-1-3	63.5 (2.5)	561 (550)	925 (208)	Cover Laminate Compression
5-4B-1-4	63.5 (2.5)	294 (70)	1526 (343)	Cover Laminate Compression
5-4B-1-5	63.5 (2.5)	294 (70)	1349 (303)	Cover Laminate Compression
5-4B-1-6	63.5 (2.5)	294 (70)	1357 (305)	Cover Laminate Compression

attachment angles (i.e., the angles pulled off). Failed specimens are shown in Figures 2-15 and 2-16.

Two of the elevated temperature (561 K (550°F)) Type 4 bonded joints exceeded the minimum design requirement of 854N (192 lbs); however, the third specimen failed at 792 N (178 lbs). Of the two specimens that exceeded the design requirement, one (5-4A-1-1) had a combined cohesive and interlaminar tension failure at the attach angle to cover interface. The specimen (5-4A-1-3) that did not meet the design load requirement had an identical failure mode. The specimen (5-4A-1-2) with the highest failure load had a compressive failure in the outer laminate of the cover outside the joint area. Typical failed specimens are shown in Figures 2-17 and 2-18.

The interlaminar tension failure of the attach angles on the Type 4 bonded joints was not as expected. Results of small specimen tests of double 90° angle attachments showed average failure loads of 40.6 N/mm (232 lbs/in) and 48.3 N/mm (276 lbs/in) at room temperature and 561 k (550°F) respectively. The Type 4 bonded joint attachment angles failed at 20 N/mm (114 lbs/in) at room temperature and at an average of 12.3 N/mm (70 lbs/in) at 561 K (550°F). This large difference in failure load is attributed to the large deflection, up to 21.3 mm (0.84 in), and correspondingly larger surface strains, experienced in the static discriminator tests. Since such large deflection would not be experienced in actual aerospace hardware, a special test was conducted using a spare Type 4 bonded joint. The support span of 423 mm (16.66 in) shown in Figure 2-14 was changed to 80 mm (3.15 in). The resulting failure load was 2.67 kN (600 lbs) or 35 N/mm (200 lbs/in) which is well above the design requirement. Based on these results, no design changes are planned for the Type 4 joints; however, the support span to be used for test will be selected to reduce design conservatism and to promote failure in the basic skin outside the joint area.

All of the Type 4 bolted joints exceeded their minimum design requirement of 712 N (160 lbs). The specimens failed in compression in the outer laminate of the cover outside the joint area. A typical failed specimen is shown in Figure 2-19.

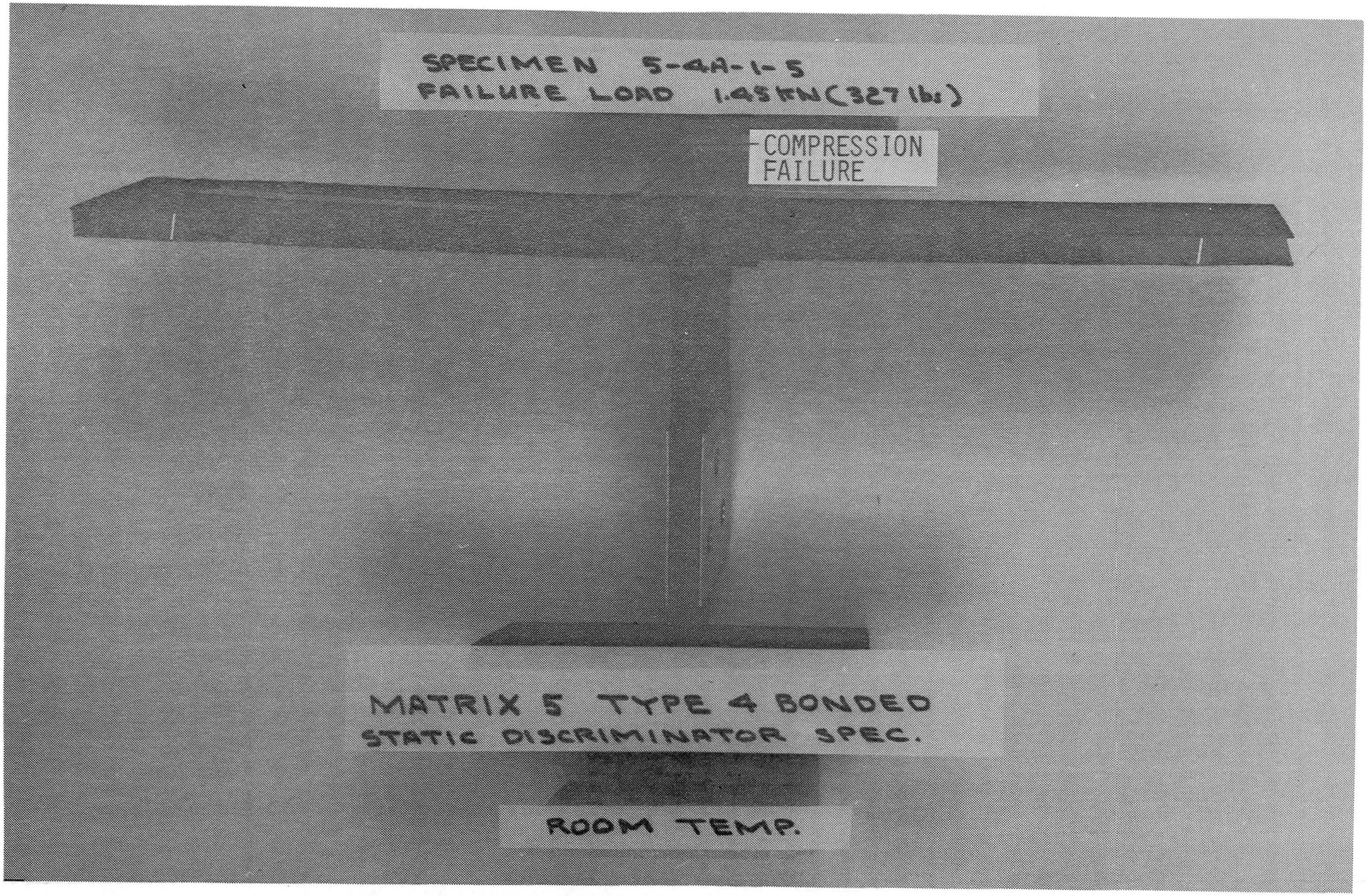


Figure 2-15: Static Discriminator Tests Type 4 Bonded Room Temperature
Cover Compression Failure

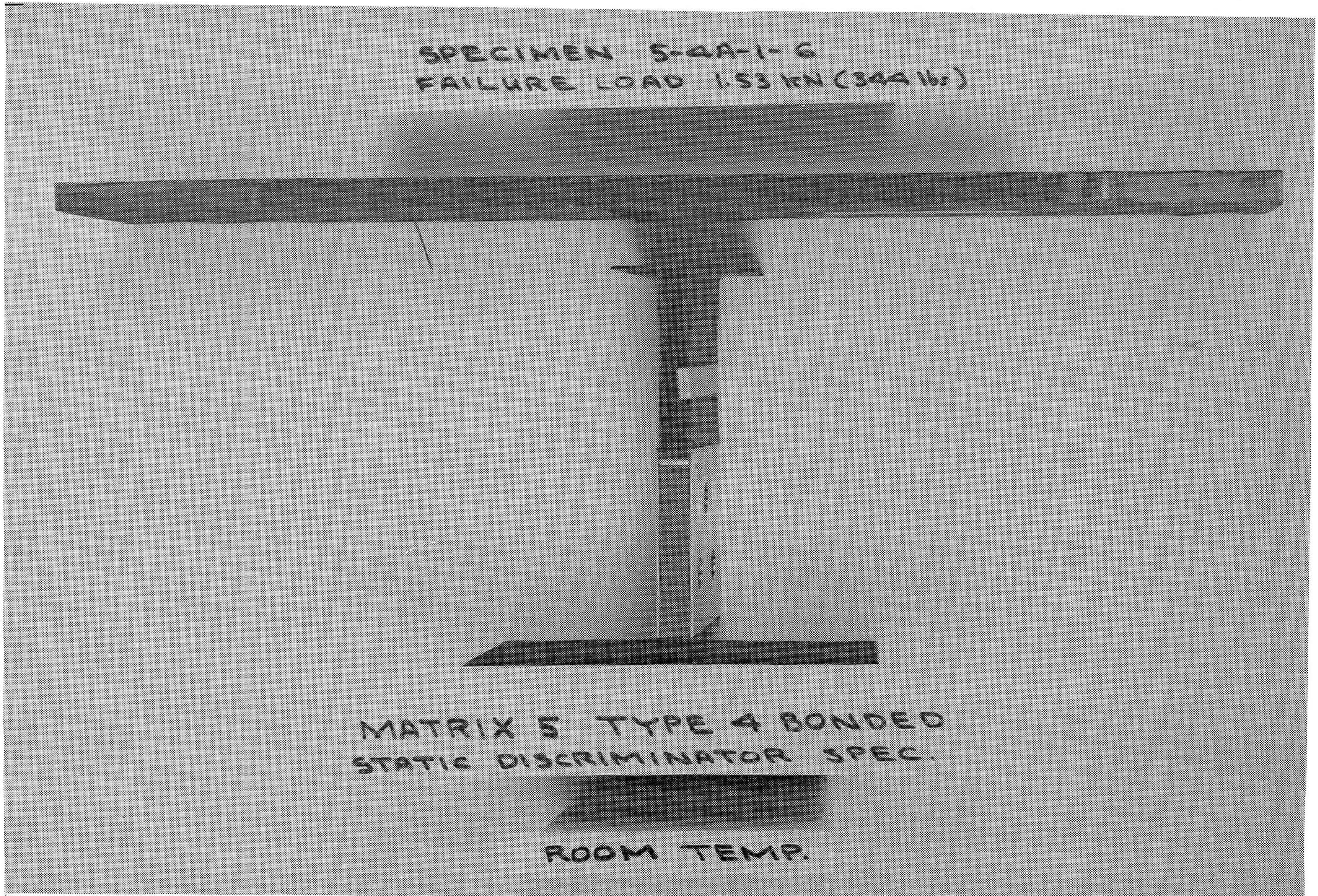


Figure 2-16: Static Discriminator Tests Type 4 Bonded Room Temperature Attach Angle Failure

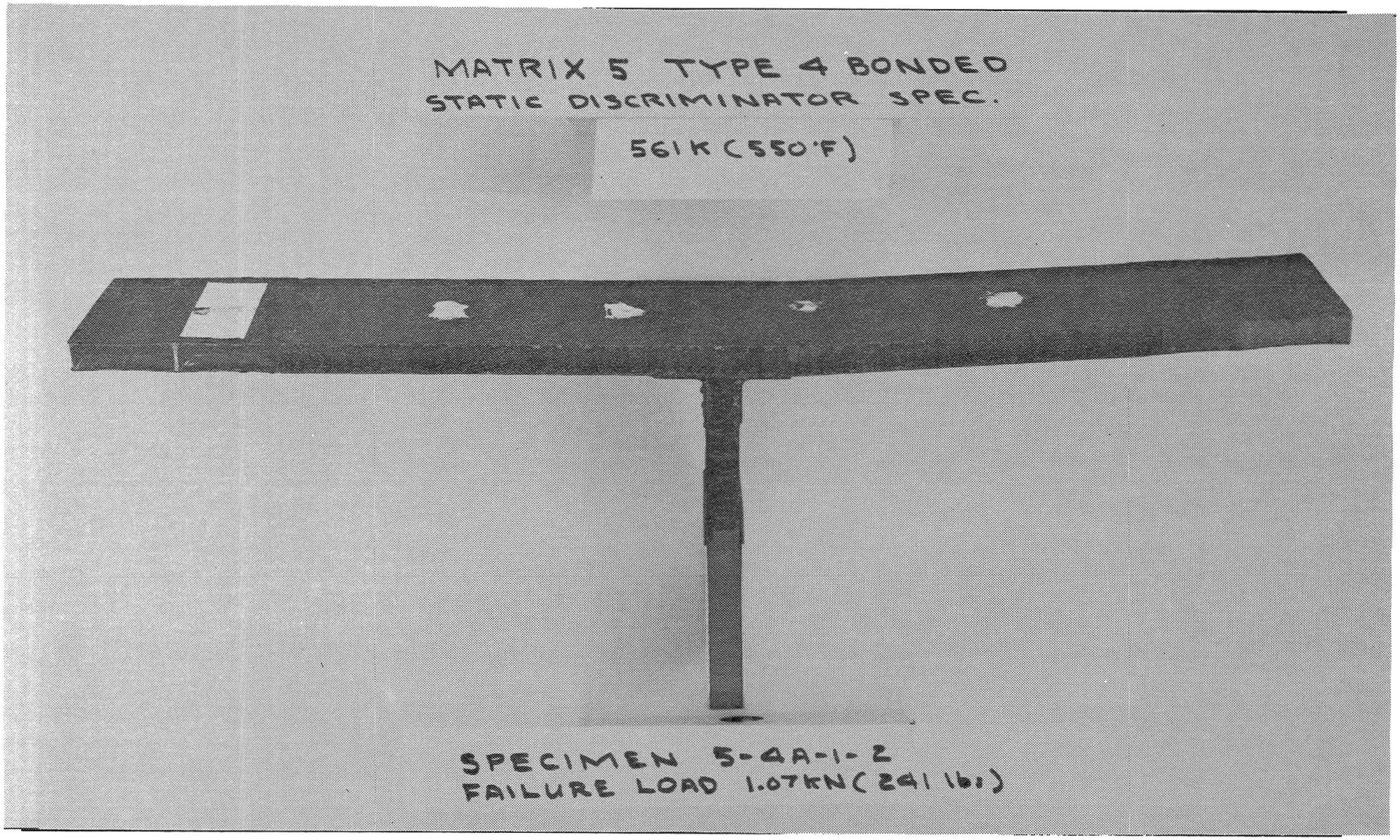


Figure 2-17: Static Discriminator Tests Type 4 Bonded 561K (550°F) Cover Compression Failure

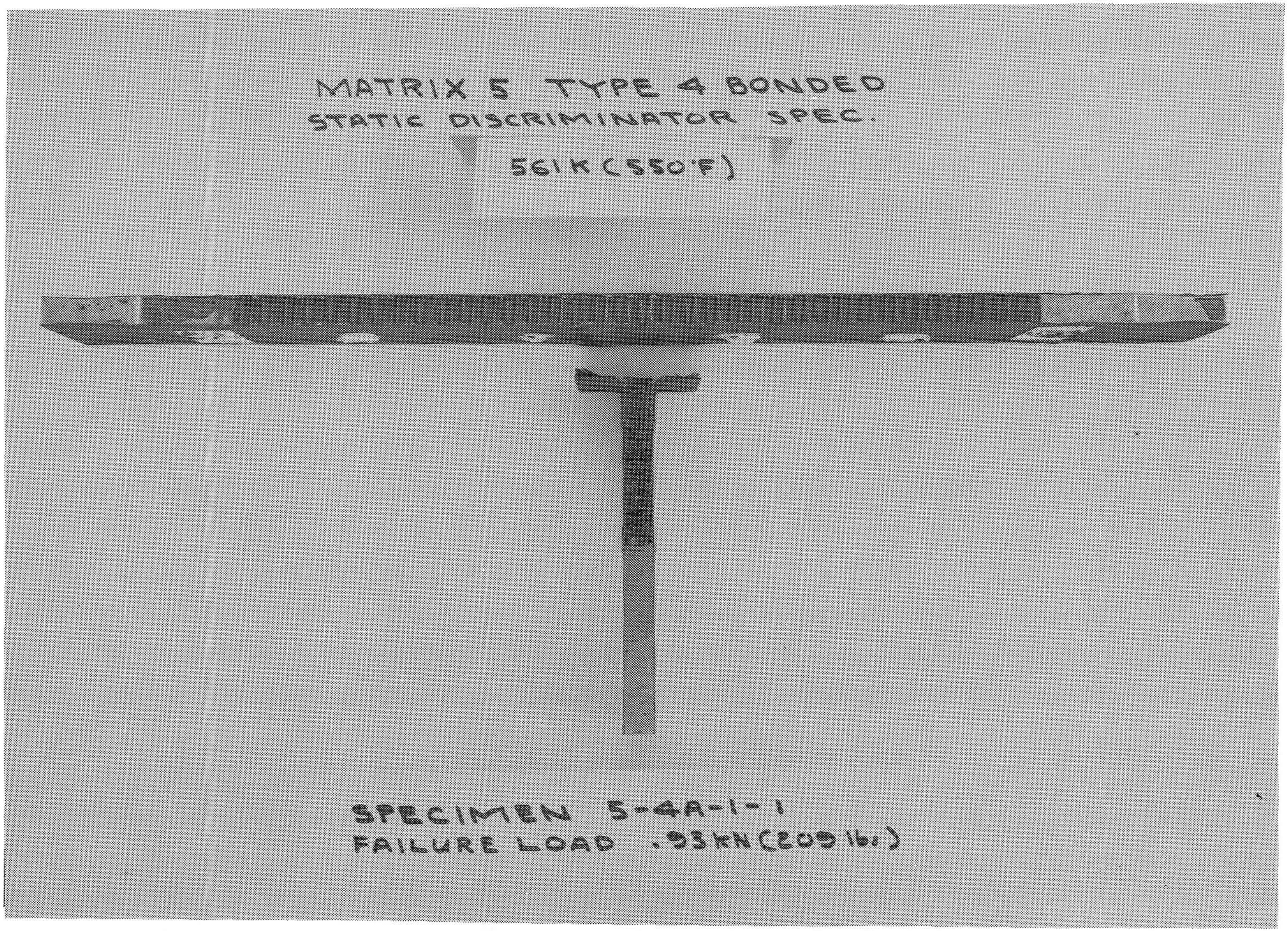


Figure 2-18: Static Discriminator Tests Type 4 Bonded 561K (550°F) Attach Angle Failure

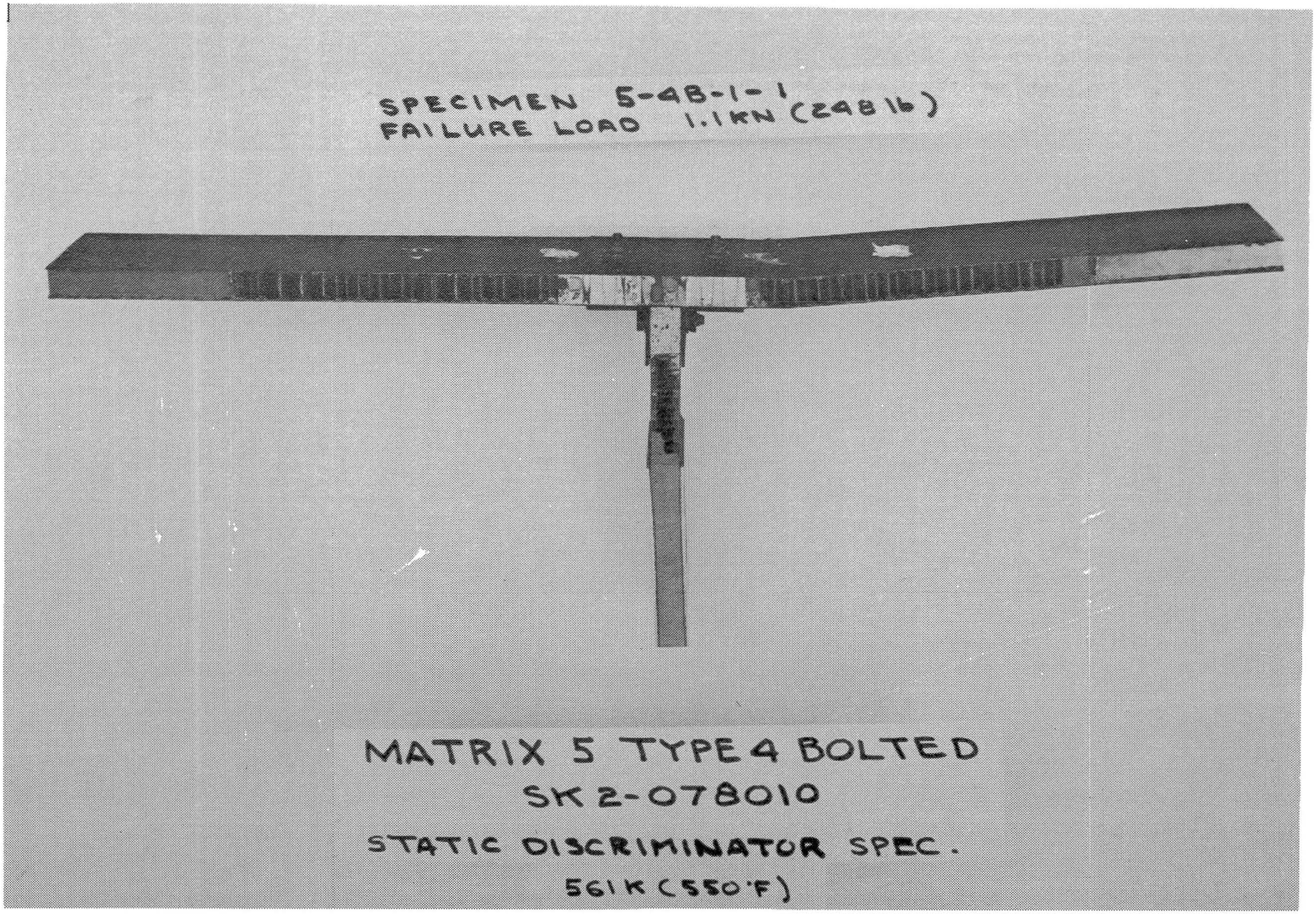


Figure 2-19: Static Discriminator Tests Type 4 Bolted Typical Failure

2.3.3 Special Interleaved Doublers

Tests of special interleaved doubler specimens to evaluate proposed design changes to the Type 1 bonded and bolted joints have been completed. Doubler lay-ups and specimen configurations are shown in Figures 2-20 and 2-21 respectively. Test results are summarized in Table 2-4. In all cases the specimens failed in the basic laminate away from the doubler area (see Figure 2-22). It is concluded that the interleaved doubles will eliminate the interlaminar shear failure experienced in the Type 1 static discriminator tests (Ref. 7th Quarterly Report No. CR159114 dated 15 April 1981) and will be used for the final designs in TASK 1.4.

2.4 TASK 1.4 - Final Evaluation of Attachment Concepts

Type 1 and Type 2 bonded and bolted joint designs have been modified to reflect results of the static discriminator tests. Type 1 bonded and bolted joints were changed by incorporating interleaved doublers to eliminate premature failure due to interlaminar shear at the doubler to skin interface. Special small specimens of interleaved doublers were built and tested to verify this design fix (see section 2.3.3). The corner angles on Type 2 bolted joints were reduced in thickness to reduce design conservatism. Skin doublers were eliminated on the Type 2 bonded joints because test results indicated they are not required.

Drawings of the Type 1 and Type 2 bonded and bolted joint designs are shown in Figures 2-23 through 2-26 and have been approved by NASA.

The Type 3 bolted joint design has been changed slightly to improve processing. The bolt pad-up area is fabricated in 3 pieces as compared to the previous 2 pieces. Interleaved pad-ups on the basic skin are a reduced thickness and the difference in thickness is made up with a separately cured filler piece. The sandwich assembly is then secondarily bonded together. The joint design is shown in Figure 2-27. A single joint will be made that is long enough to cut out the required number of static test specimens.

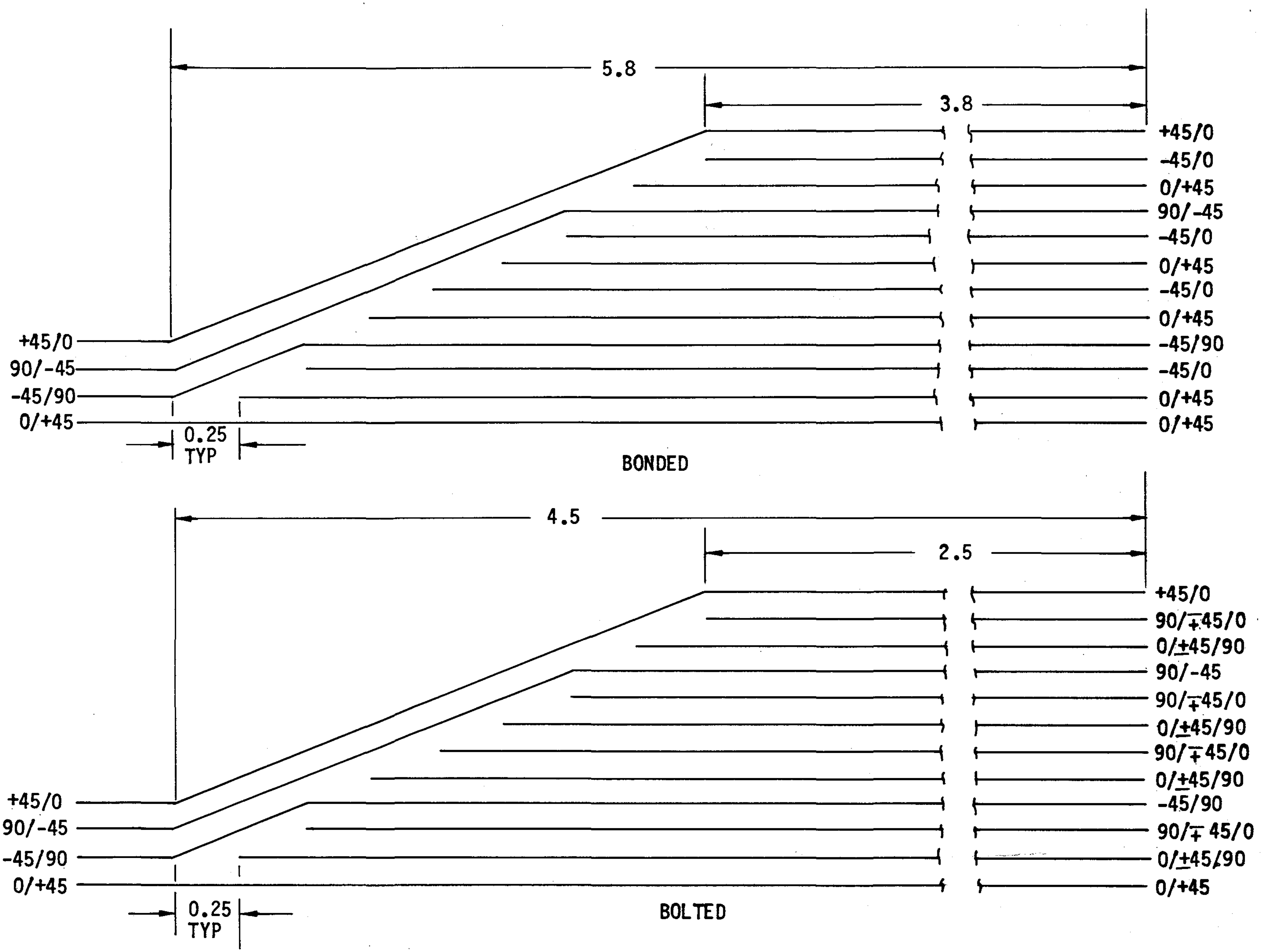


Figure 2-20: Interleaved Doubler Layups, Static Discriminator
Type 1 Joints - Alternate Design

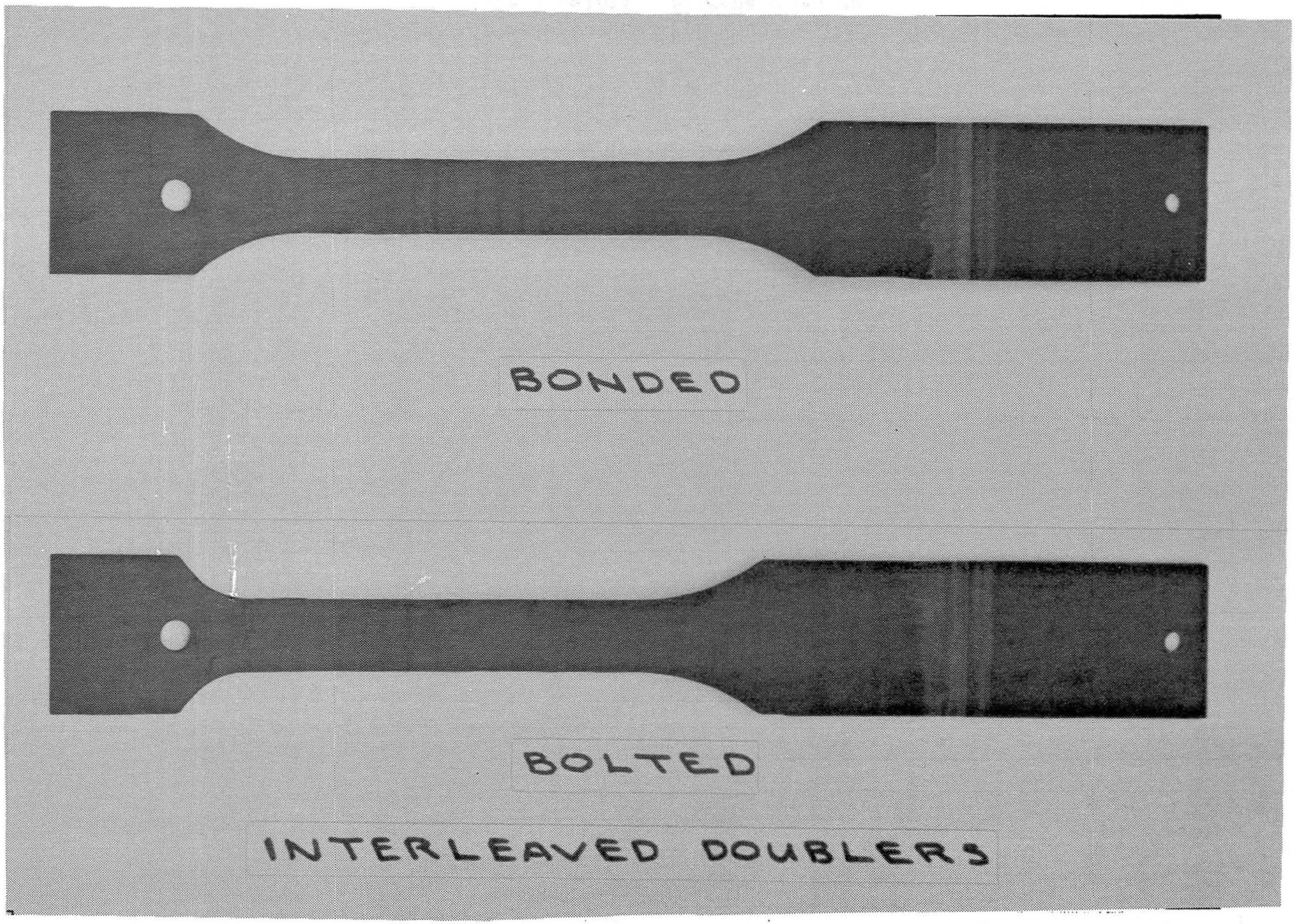


Figure 2-21: Interleaved Double Test Specimens

Table 2-4 Special Interleaved Doublers

Matrix 5 - Static Discriminator Tests

SPECIMEN NO.	TYPE	TEMPERATURE K (°F)	FAILURE LOAD kN (lbs)	LAMINATE STRESS Mpa (ksi)
5-6A-1-4	Bonded	294 (70)	6.1 (1365)	492 (71.3)
5-6A-1-5	Bonded	561 (550)	5.3 (1195)	434 (62.9)
5-6A-1-6	Bonded	561 (550)	6.0 (1360)	492 (71.4)
5-6A-1-7	Bonded	561 (550)	6.2 (1395)	496 (72.0)
5-6B-1-1	Bolted	294 (70)	6.2 (1400)	497 (72.1)
5-6B-1-2	Bolted	294 (70)	6.0 (1350)	490 (71.0)
5-6B-1-3	Bolted	294 (70)	5.2 (1170)	437 (63.4)
5-6B-1-4	Bolted	561 (550)	6.4 (1445)	496 (71.9)
5-6B-1-5	Bolted	561 (550)	6.9 (1560)	532 (77.2)
5-6B-1-6	Bolted	561 (550)	6.5 (1460)	523 (75.9)

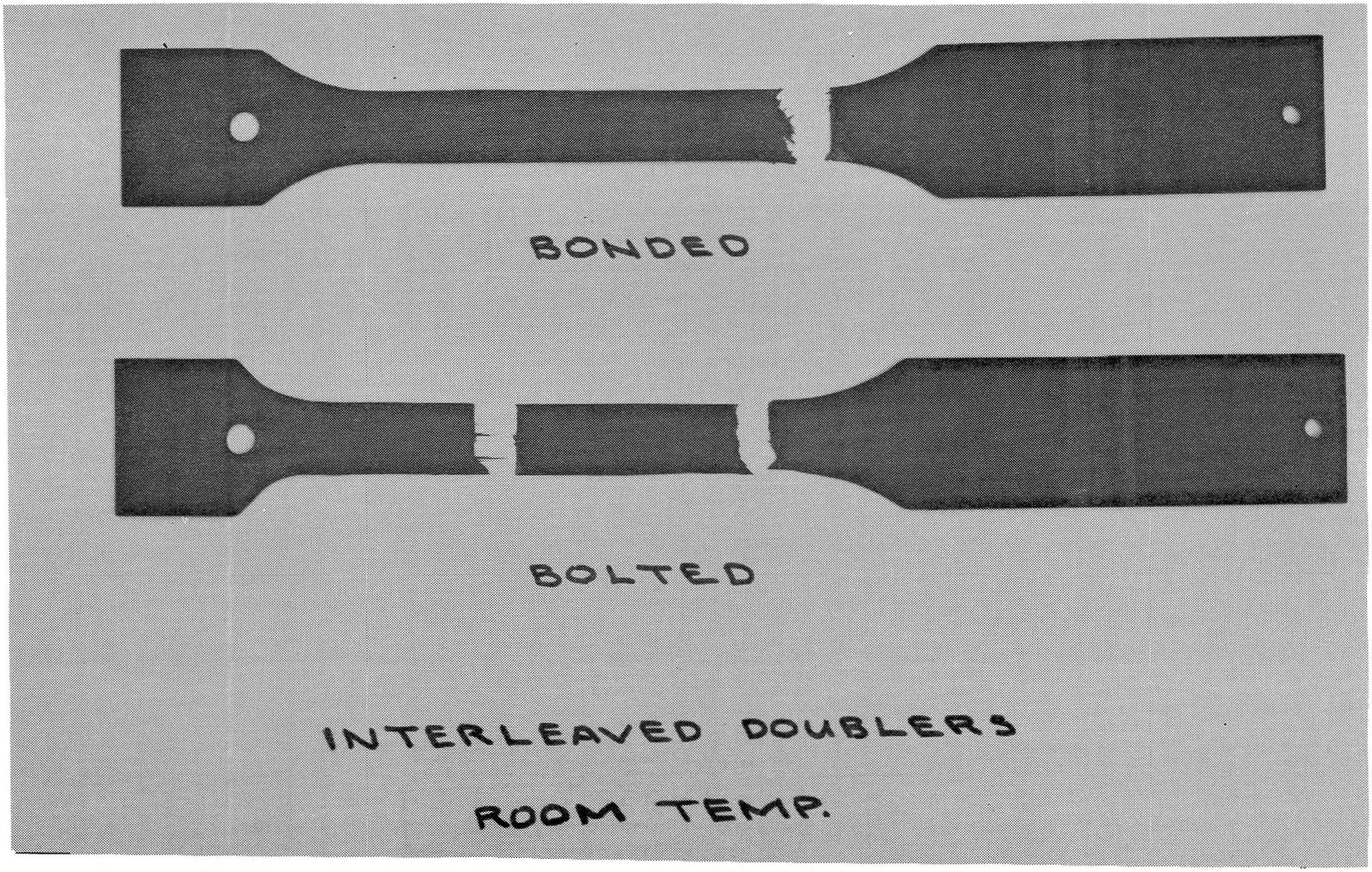


Figure 2-22: Typical Failures - Interleaved Doublers

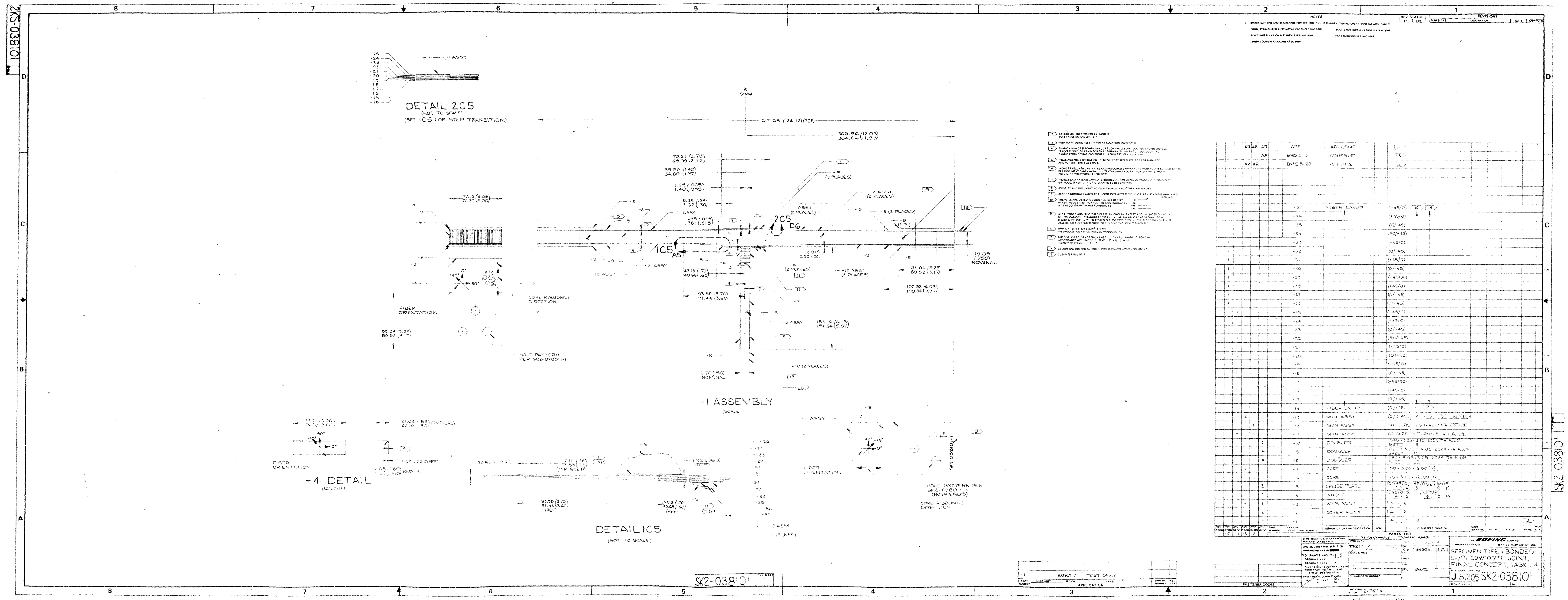

DETAIL 2C5
(NOT TO SCALE)
(SEE 1C5 FOR STEP TRANSITION)
-1 ASSEMBLY
-4 DETAIL
DETAIL 1C5
(NOT TO SCALE)
FIBER ORIENTATION
CORE RIBBON(L) DIRECTION
HOLE PATTERN PER SK2-078011-1
NOTES
PARTS LIST
THE BOEING COMPANY
SPECIMEN TYPE I BONDED
Gr/Pi COMPOSITE JOINT,
FINAL CONCEPT, TASK 1.4
J 81205 SK2-038101
SK2-038101

Figure 2-23

NOTES

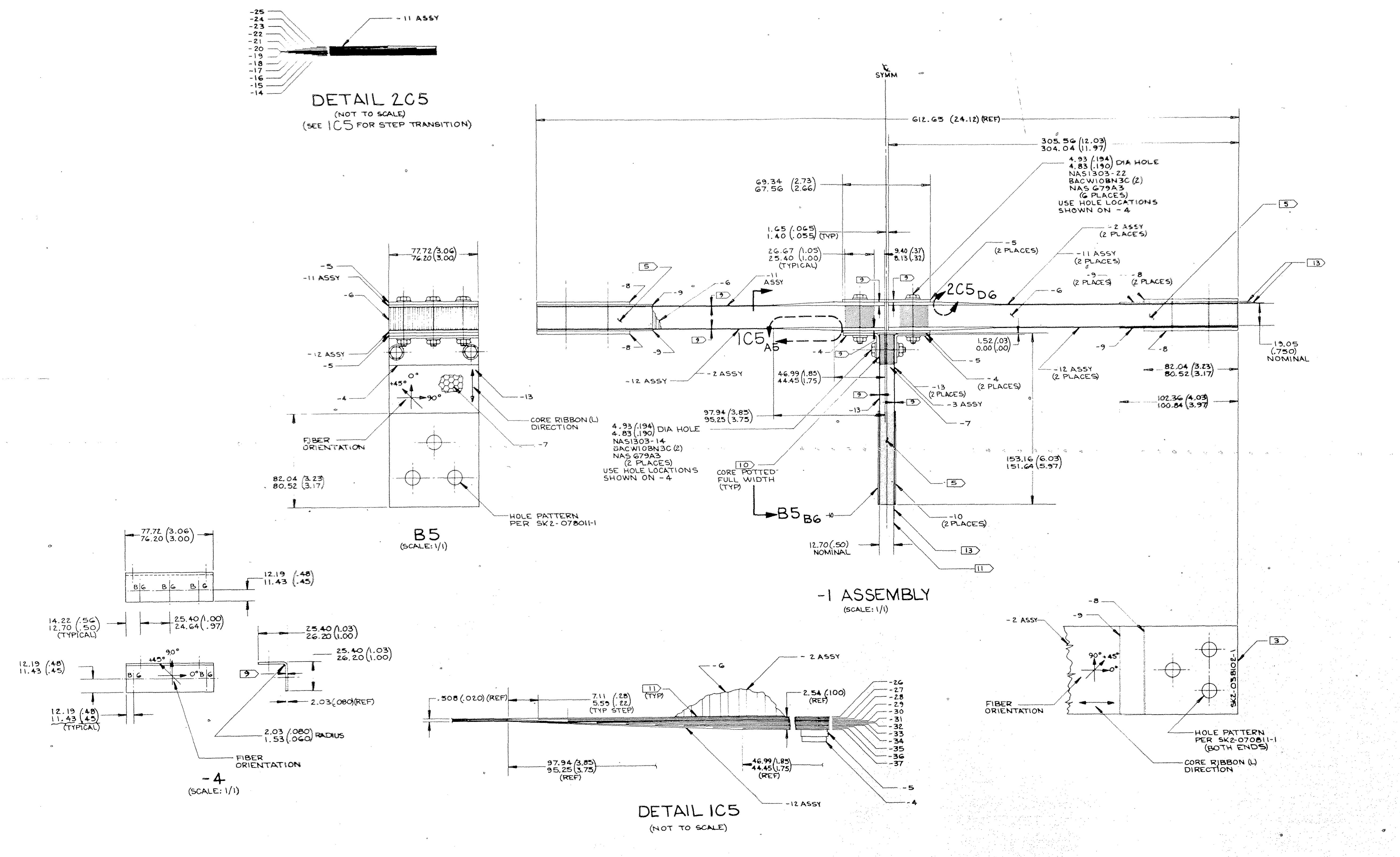
SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009

RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307

FINISH CODES PER DOCUMENT D7 5000

REV STATUS		REVISIONS				
SH	LTR	ZONE	LTR	DESCRIPTION	DATE	APPROVED



2 XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ON ANGLES ±1°

3 PART MARK USING FELT TIP PEN AT LOCATION INDICATED

4 FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180 20545 5A "PROCESS SPECIFICATION FOR PMR 15 GRAPHITE PREPREG" DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION

5 FINAL ASSEMBLY OPERATION. REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5 28 TYPE 8

6 INSPECT PRECURED LAMINATES AND PRECURED LAMINATE TO HONEYCOMB BONDED JOINTS PER DOCUMENT D180 20545 6 "NDI TESTING PROCEDURES FOR GRAPHITE PMR 15 POLYIMIDE STRUCTURAL ELEMENTS"

8 IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES

9 RECORD NOMINAL LAMINATE THICKNESSES AFTER POSTCURE AT LOCATIONS INDICATED

10 BMS 8 126 TYPE 1 POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE OVER THE AREA DESIGNATED PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8 126

11 A7F BLENDED AND PROCESSED PER D180 20545 5A EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB O SIL. TITANIUM TO TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSEMBLY

12 HRH 327 - 3/16-8 (128.2 kg/m³ (8 lb/ft³)) FIBERGLASS/POLYIMIDE. HEXCEL PRODUCTS INC

13 BMS 5 51 TYPE 2 GRADE 10 OR BMS 5 101 TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514 ITEMS -8, -9 & -10 TO ASSY OF ITEMS -2 & -3

14 CELION 3000 (NR 150B2G FINISH) PMR 15 PREPREG PER D180 20545 4A

15 TIGHTEN NUTS WITHIN TORQUE RANGE OF 18 TO 20 INCH POUNDS

16 CLEAN PER BAC 5514

17 STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811 TYPE VIII CLASS I

18 THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE PART NUMBER ARROW, e.g. — (0/90/±45): 0, 90, +45, 45

PARTS LIST

QTY REQD	QTY REQD -12	QTY REQD -11	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT	FINISH	PT MK	REV LTR
					AR		BMS 5-28	POTTING		5					
			AR	AR			A7F	ADHESIVE		11					
					AR		BMS 5-51	ADHESIVE		13					
			AR	AR			BMS 8-126	POTTING		10					
					16		BACW10BN-3C	WASHER							
					8		NAS679A3	NUT		17					
					6		NAS1303-22	BOLT		17					
					2		NAS1303-14	BOLT		17					
	1						-37	FIBER LAYUP		(-45/0) 14 18					
	1						-36			(90/±45/0)					
	1						-35			(0/±45/90)					
	1						-34			(90/+45)					
	1						-33			(90/±45/0)					
	1						-32			(0/±45/90)					
	1						-31			(90/±45/0)					
	1						-30			(0/±45/90)					
	1						-29			(+45/90)					
	1						-28			(90/±45/0)					
	1						-27			(0/±45/90)					
	1						-26			(0/-45)					
		1					-25			(+45/0)					
		1					-24			(90/±45/0)					
		1					-23			(0/±45/90)					
		1					-22			(90/-45)					
		1					-21			(90/±45/0)					
		1					-20			(0/±45/90)					
		1					-19			(90/±45/0)					
		1					-18			(0/±45/90)					
		1					-17			(-45/90)					
		1					-16			(90/±45/0)					
		1					-15			(0/±45/90)					
		1					-14	FIBER LAYUP		(0/+45) 14 18					
			2				-13	SKIN ASSY		$(0/\pm45)_S$ 4 6 9 14 18					
	–			1			-12	SKIN ASSY		CO-CURE -26 THRU -37 4 6 9					
		–		1			-11	SKIN ASSY		CO-CURE -14 THRU -25 4 6 9					
					2		-10	DOUBLER		.040 × 3.05 × 3.25 2024-T4 ALUM SHEET 16					
					4		-9	DOUBLER		.020 × 3.05 × 4.05 2024-T4 ALUM SHEET 16					
					4		-8	DOUBLER		.080 × 3.05 × 3.25 2024-T4 ALUM SHEET 16					
			1				-7	CORE		.50 × 3.00 × 6.00 12					
		1					-6	CORE		.75 × 3.00 × 12.00 12					
					2		-5	SPLICE PLATE		$(0/\pm45/90)_{5S}$ LAYUP 9 14 18					
					2		-4	ANGLE		$(0/\pm45/90)_{4S}$ LAYUP 9 14 18					
		–			1		-3	WEB ASSY		4 6					
			–		2		-2	COVER ASSY		4 6					
					–		-1	SPECIMEN, TYPE I BOLTED ASSEMBLY		8				3	

DIMENSIONING & TOLERANCING PER ANSI (USASI) Y14.5

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCES: ANGLES ± 2

CONTRACT NUMBER NAS1-15644

DRN K.W. OSBORNE 3-27-81

THE BOEING COMPANY — CORPORATE OFFICES, SEATTLE WASHINGTON 98124

SPECIMEN, TYPE I, BOLTED Gr/Pi COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

SIZE J — CODE IDENT NO 81205 — SK2-038102

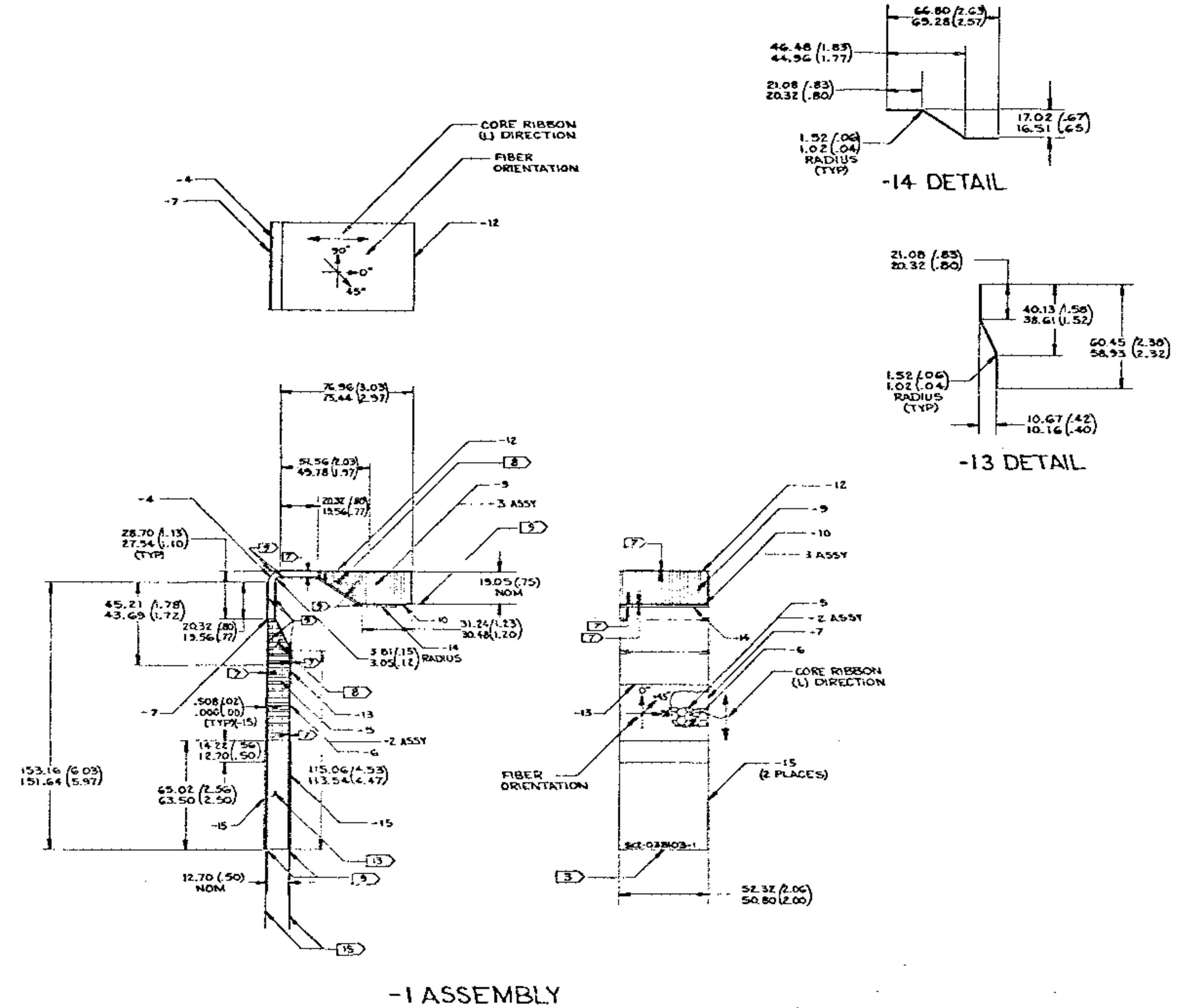
-1		MATRIX 7	TEST ONLY		
PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG NUMBER	REV LTR
		APPLICATION			

FASTENER CODES

SK2-038102

SK2-038102

Figure 2-24



NOTES

1. [illegible]
2. XX.XXX MILLIMETERS (X.XX INCHES) TOLERANCE ON ANGLES: ±1°
3. PART MARK USING [illegible] PER AT LOCATION INDICATED.
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
6. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.
7. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
8. BMS 8-126 TYPE II POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.
9. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1X (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 PSI. WHEN TESTED PER BSS 7202, TYPE V, THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
10. HRH-327-3/16-8 (128.2 kg/m³ (8 lb/ft³)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
11. HRH-327-3/16-4 (64.1 kg/m³ (4 lb/ft³)), FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
12. CELION 3000 (NR 150B2 FINISH)/PMR-15 PREPREG PER D180-20545-4A.
13. FINAL ASSEMBLY OPERATION. REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 1.
14. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.: (+45/-45/90/0)
15. BOND -15 TO -2 ASSY WITH BMS 5-104, PER BAC 5514.
16. INSPECT LAMINATE TO LAMINATE BONDED JOINTS USING ULTRASONIC "C" SCAN TEST METHODS. SENSITIVITY OF "C" SCAN TO BE DETERMINED.

PARTS LIST

QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	MATERIAL AND SPECIFICATION
			AR	AR	AR	A7F	ADHESIVE	9
					AR	BMS 5-104	ADHESIVE	15
			AR	AR		BMS 8-126	POTTING	8
					AR	BMS 5-28	POTTING	13
				2		-15	TAB, REINFORCEMENT	.040 (REF) 4 LAYERS FABRIC BMS 8-139
					1	-14	REINFORCEMENT	.040 (REF) $(0,\pm45,90)_{2S}$ LAYUP 5 12 14
					1	-13	REINFORCEMENT	.030 (REF) $(0,\pm45)_{2S}$ LAYUP 5 12 14
			1			-12	SKIN	.020 (REF) $(0,\pm45,90)_S$ LAYUP 5 12 14
			1			-10	SKIN	.020 (REF) $(0,\pm45,90)_S$ LAYUP 5 12 14
			1			-9	CORE	.75 × 2.05 × 3.25 10
				1		-7	SKIN	.015 (REF) $(0,\pm45)_S$ LAYUP 5 12 14
				1		-6	SKIN	.015 (REF) $(0,\pm45)_S$ LAYUP 5 12 14
				1		-5	CORE	.50 × 2.05 × 5.25 11
					1	-4	ANGLE	.120 (REF) $(0,\pm45,90)_{6S}$ LAYUP 5 12 14
			-		1	-3	COVER ASSY	4 5
				-	1	-2	WEB ASSY	4 5
					-	-1	SPECIMEN, TYPE 2, BONDED ASSY	4 6 16

CONTRACT NUMBER NAS1-15644

K.W. OSBORNE

THE BOEING COMPANY

SPECIMEN, TYPE 2, BONDED-Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

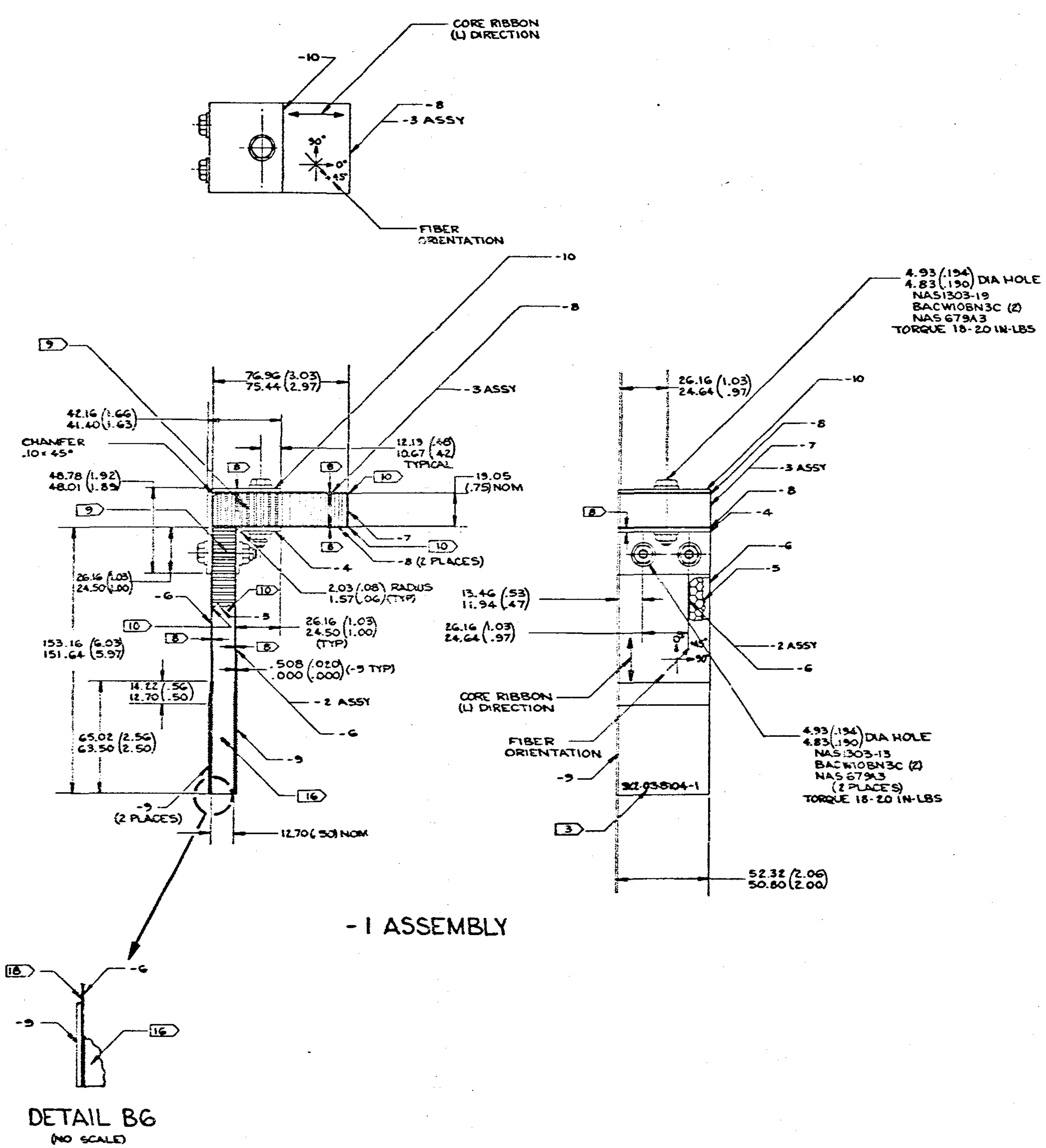
J 81205 SK2038103

TEST ONLY

APPLICATION

FASTENER CODES

Figure 2-25



NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE).
   FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009
   RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307
   FINISH CODES PER DOCUMENT D2-8000

2. XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ANGLES: ±1°
3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDT TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
7. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.
8. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
9. BMS 8-126 TYPE 1, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.
10. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi. WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
11. HRH-327 -3/16-8 (128.2 kg/m^3 (8 lb/ft^3)). FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
12. HRH-327-3/16-4 (64.1 kg/m^3 (4 lb/ft^3)), FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
14. CELION 3000 OR 150B26 FINISH/PMR-15 PREPREG PER D180-20545-4A.
15. STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.
16. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 6.
17. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.,
    (0/90/±45)
    0
    90
    +45
    -45
18. BOND ITEM -9 TO -2 ASSY WITH BMS 5-104 PER BAC 5514

PARTS LIST

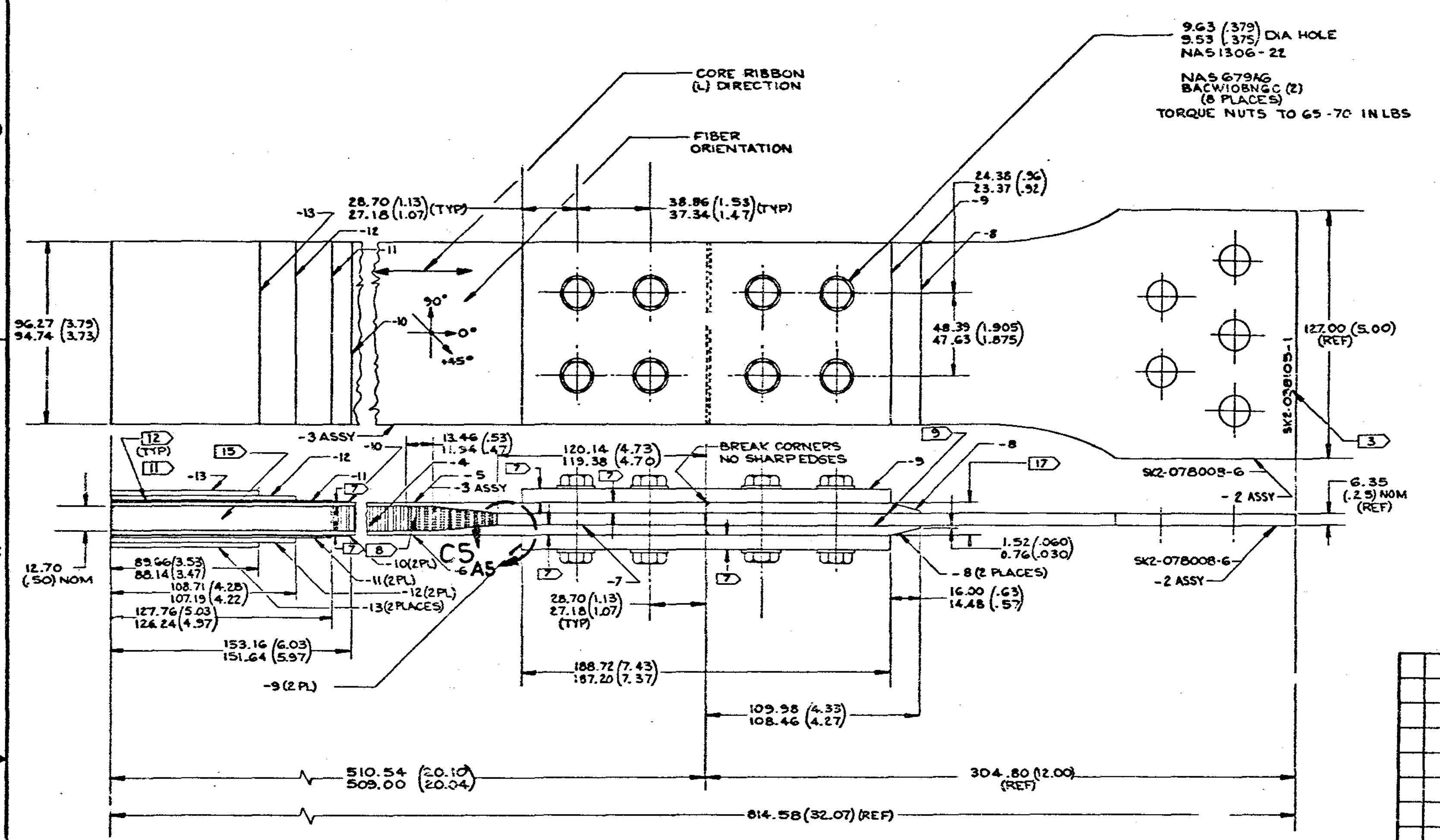
QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT TR	FINISH	PT BK	REV LTR
			AR	AR			BMS8-126	POTTING		9					
				AR			BMS 5-28	POTTING		16					
			AR	AR			A7F	ADHESIVE		10					
				AR			BMS 5-104	ADHESIVE		18					
					6		BACW10BN3C	WASHER		15					
					3		NAS679-3	NUT		15					
					1		NAS1303-19	BOLT		15					
					2		NAS1303-13	BOLT		15					
					1		-10	ANGLE, CORNER		.080 (REF) (0,±45,90)$_{4S}$ LAYUP 14 17 5					
				2			-9	REINFORCEMENT		.040 (REF) 4 LAYERS FABRIC, BMS 8-139					
			2				-8	SKIN		.020 (REF) (0,±45,90)$_S$ LAYUP 14 17 5					
			1				-7	CORE		.75 × 2.05 × 3.05 11					
				2			-6	SKIN		.015 (REF) (0 ±45)$_S$ LAYUP 14 17 5					
				1			-5	CORE		.50 × 2.05 × 6.05 12					
					1		-4	ANGLE CLIP		.060 (REF) (0,±45,90)$_{3S}$ LAYUP 14 17 5					
			—		1		-3	COVER ASSY		4 5					
				—	1		-2	WEB ASSY		4 5					
					—		-1	SPECIMEN, TYPE 2, BOLTED ASSY		4 7				3	

CONTRACT NUMBER NAS1-15644
DR K. W. OSBORNE 4-7-81
THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON
SPECIMEN, TYPE 2, BOLTED-Gr/Pi COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4
J 81205 SK2-038104
SCALE 1/1

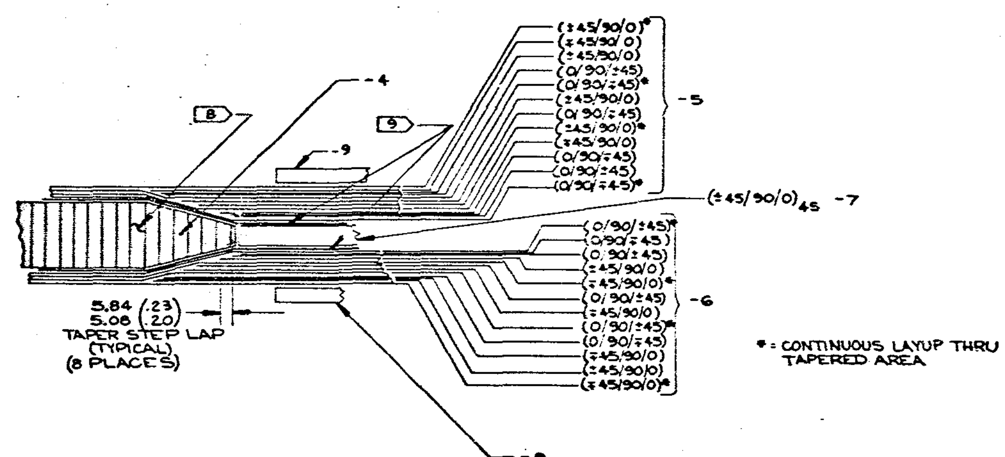
TEST ONLY
APPLICATION

FASTENER CODES

Figure 2-26



- 1 ASSEMBLY
(SCALE: 1/1)



DETAIL C5
(NO SCALE)

NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
   FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009
   RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307
   FINISH CODES PER DOCUMENT D2 0000

2. XX, XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ANGLES: ±1°
3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED.
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
6. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMALIES.
7. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
8. BMS 8-126 TYPE I, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.
9. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi. WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
10. HRH-327-3/16-4 (64.1 kg/m^3 (4lb/ft^3)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
11. CAUTION DO NOT DAMAGE OUTER PLY WHEN PREPARING LAMINATE SURFACE FOR BONDING
12. BMS 5-51, TYPE 2, GRADE 10 OR BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -11, -12, & -13 TO -3 ASSY
13. CELION 6000 (NR 150B26 FINISH)/PMR-15 PREPREG PER D180-20545-4A.
14. STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.
15. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 6.
16. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.,
    (0/90/±45)
    0
    90
    +45
    -45
17. AFTER BONDING -8 TO SK2-078008-6 THIS THICKNESS SHALL BE CHEM-MILLED TO MATCH TOTAL THICKNESS OF THE -3 COVER ASSY
18. 6AL-4V TITANIUM PLATE PER MIL-T-9046, TYPE III, COMP C, ANNEALED
19. CLEAN PER BAC 5514

PARTS LIST

QTY REQD	QTY REQD	QTY REQD	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT TR	FINISH	PT MK	REV LTR
				1			SK2-078008-6	PLATE							
					16		BACW10BNGC	WASHER		14					
					8		NAS679A6	NUT		14					
					8		NAS1306-22	BOLT		14					
			AR	AR			A7F	ADHESIVE		9					
			AR				BMS 8-126	POTTING		8					
					AR		BMS 5-51	ADHESIVE		12					
			AR				BMS 5-28	POTTING		15					
					2		-13	REINFORCEMENT		.100 × 3.85 × 3.25 2024-T4 ALUM SHEET 12 19					
					2		-12	REINFORCEMENT		.100 × 3.85 × 4.05 2024-T4 ALUM SHEET 12 19					
					2		-11	REINFORCEMENT		.050 × 3.85 × 4.85 2024-T4 ALUM SHEET 12 19					
					2		-10	REINFORCEMENT							
					2		-9	SPLICE PLATE		(0, ±45, 90)$_{7S}$ LAYUP 5 13 16					
				2			-8	DOUBLER		.250 × 3.85 × 4.30 18					
			1				-7	FILLER		LAYUP (SEE DET C5) 5 13					
			1				-6	SKIN ASSY		LAYUP (SEE DET C5) 5 13					
			1				-5	SKIN ASSY		LAYUP (SEE DET C5) 5 13					
			1				-4	CORE		.50 × 3.80 × 14.00 10					
					1		-3	COVER ASSY		4 5					
				–	1		-2	PLATE ASSY		6 9					
					–		-1	SPECIMEN, TYPE 3, BOLTED Gr/Pi SPLICE PLATE		4 6				3	

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG IN NUMBER	REV LTR
		TEST MATRIX 7	TEST ONLY		

APPLICATION

FASTENER CODES

CONTRACT NUMBER NAS1-15644

DRAWN E.W. OSBORNE

THE BOEING COMPANY, SEATTLE, WASHINGTON

SPECIMEN, TYPE 3, BOLTED-Gr/Pi COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

SIZE J CODE IDENT NO 81205 SK2-038105

SCALE NOTED

DWG ORIG BY (ORG) 2-3614

SK2-038105

2KS038102

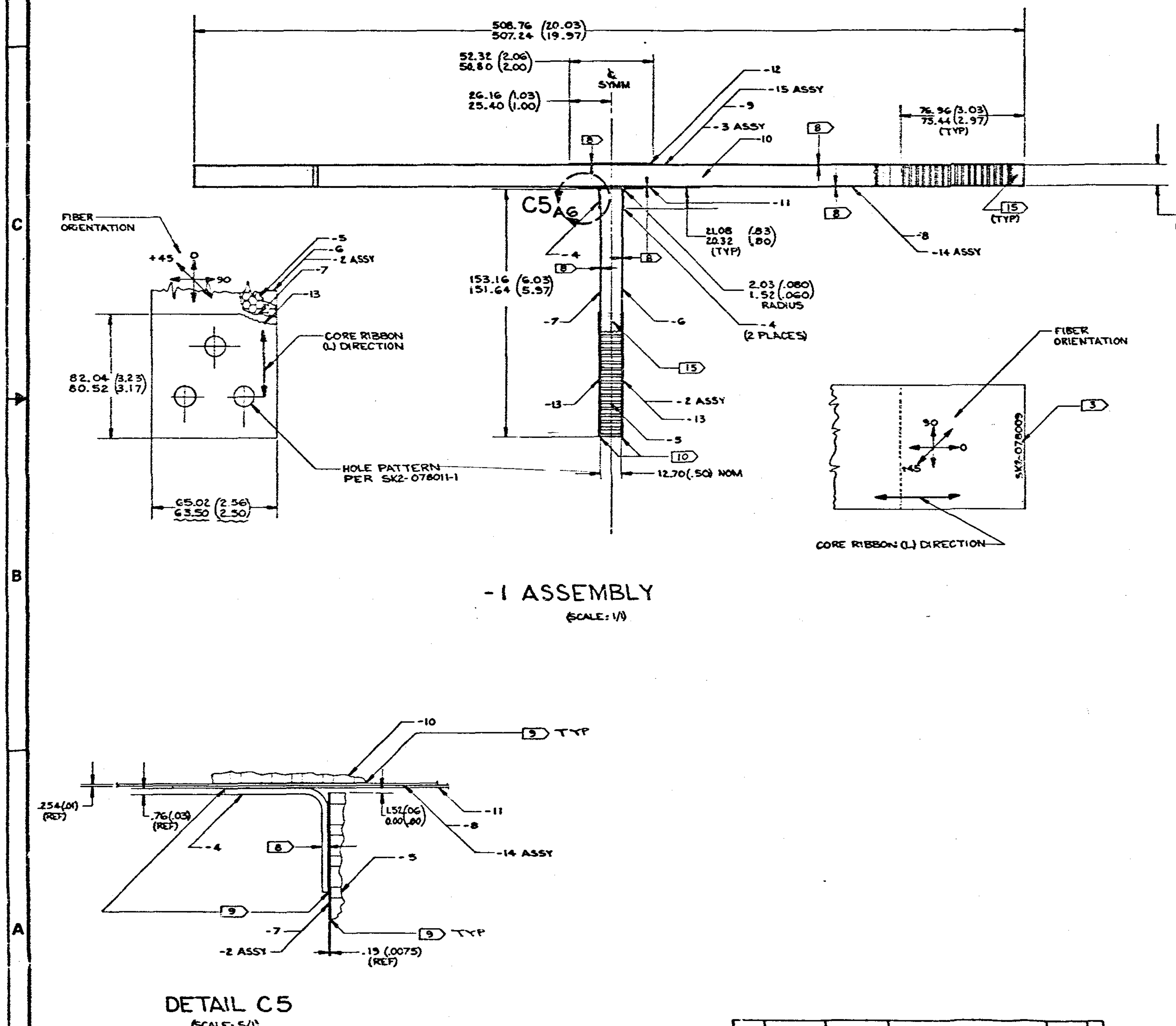
Figure 2-27

A special specimen design is required for the fatigue tests because it requires bolted grips on both ends in order to interface with the fatigue test machine. The specimen configuration is show in Figure 2-28. It incorporates a symmetric specimen that has a bolted joint on each end. One end will use a graphite polyimide splice plate and the other end a titanium splice plate. This will enable both Type 3 bolted joint concepts to be fatigue tested simultaneously. The specimens, however, are only one bolt spacing wide and will be cut from a different joint panel lay-up than the static strength specimens.

Type 4 bonded and bolted joint designs are shown in Figures 2-29 and 2-30 respectively. The designs are not changed from the configurations tested in the static discriminator tests and discussed in section 2.3.2.

SK2-038106
NOTES
-1 ASSEMBLY
-3 ASSY
-2 ASSY
FIBER ORIENTATION
HOLE PATTERN PER SK2-078011-1
881.19 (34.72) REF
BREAK CORNERS NO SHARP EDGES
DETAIL B5
(NOT TO SCALE)
TYPICAL TWO LOCATIONS
TAPER STEP LAP (8 PLACES) (TYPICAL)
* CONTINUOUS LAYUP OVER TOTAL LENGTH OF -5 OR -6
BACW10BN6C WASHER
NAS679A6 NUT
NAS1306-22 BOLT
NAS1306-17 BOLT
ADHESIVE
BMS 8-126 POTTING
SPLICE PLATE
DOUBLER
PLATE
FILLER
SKIN ASSY
CORE
COVER ASSY
PLATE ASSY
PARTS LIST
TEST MATRIX
TEST ONLY
APPLICATION
FASTENER CODES
THE BOEING COMPANY
SPECIMEN, TYPE 3 BOLTED-Gr/P. COMPOSITE JOINT, FATIGUE TEST, TASK I.4
81205 SK2-038106

Figure 2-28



NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)

   FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300 — BOLT & NUT INSTALLATION PER BAC 5009

   RIVET INSTALLATION & SYMBOLS PER BAC 5004 — PART MARKING PER BAC 5307

   FINISH CODES PER DOCUMENT 10-6000

2. XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE OR ANGLES: ±$\frac{1}{2}^{\circ}$
3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED.
4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPREG". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.
5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".
6. INSPECT LAMINATE TO LAMINATE BONDED JOINTS USING ULTRASONIC "C" SCAN TEST METHODS. SENSITIVITY OF "C" SCAN TO BE DETERMINED.
7. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.
8. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.
9. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi., WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.
10. BMS 5-51, TYPE 2, GRADE 10 or BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -13 TO ASSY. OF -5, -6 & -7
11. CELION 3000 (WITH 250826 FINISH)/PMR-15 PREPREG PER D180-20545-4A.
12. HRH-327 -3/16-4 (64.1 kg/m^3 (4lb/ft^3)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.
13. CLEAN PER BAC 5514.
14. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.:

   -45
   +45
   90
   0
   (0/90/±45)

15. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED POT WITH BMS 5-28 TYPE 5 OR TYPE 6.

REV STATUS

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD	QTY REQD -15	QTY REQD -14	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT TR	FINISH	PT MK	REV LTR
				AR			BMS 5-51	ADHESIVE		10					
			AR	AR	AR		A7F	ADHESIVE		9					
					AR		BMS 5-28	POTTING		15					
	–		1				-15	SKIN ASSY		CO-CURE -9 & -12 4 5 8					
		–	1				-14	SKIN ASSY		CO-CURE -8 & -11 4 5 8					
				2			-13	DOUBLER		.040×2.55×3.25 2024-T4 ALUM SHEET 13					
	1						-12	REINFORCEMENT		.010 REF (±45,90,0) LAYUP 11 14					
		1					-11	REINFORCEMENT		.010 REF (±45,90,0) LAYUP 11 14					
			1				-10	CORE		.50 × 2.50 × 20.00 12					
	1						-9	SKIN		.010 REF (0,90,±45) LAYUP 11 14					
		1					-8	SKIN		.010 REF (0,90 ±45) LAYUP 11 14					
				1			-7	SKIN		.0075 REF (±45,0) LAYUP 8 11 14 5					
				1			-6	SKIN		.0075 REF (±45,0) LAYUP 11 14 8 5					
				1			-5	CORE		.50 × 2.50 × 6.00 12					
					2		-4	ANGLE CLIP		.030 REF (±45,0,90$_3$)$_s$ LAYUP 11 14 8					
			–		1		-3	COVER ASSY		4 5					
				–	1		-2	WEB ASSY		4 5					
					–		-1	SPECIMEN, TYPE 4, BONDED ASSY		4 6 7				3	

PART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	DWG BY NUMBER	REV LTR
		TEST MATRIX 7	TEST ONLY		

APPLICATION

FASTENER CODES

DIMENSIONING & TOLERANCING PER ANSI Y14.5

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN [illegible]

TOLERANCES: ANGLES ± 2

REVIEW & APPROVAL

CONTRACT NUMBER NAS1-15644

DRN K.W. OSBORNE 6-11-81

7/7/81

THE BOEING COMPANY

CORPORATE OFFICES SEATTLE, WASHINGTON

SPECIMEN, TYPE 4, BONDED-G/P. COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

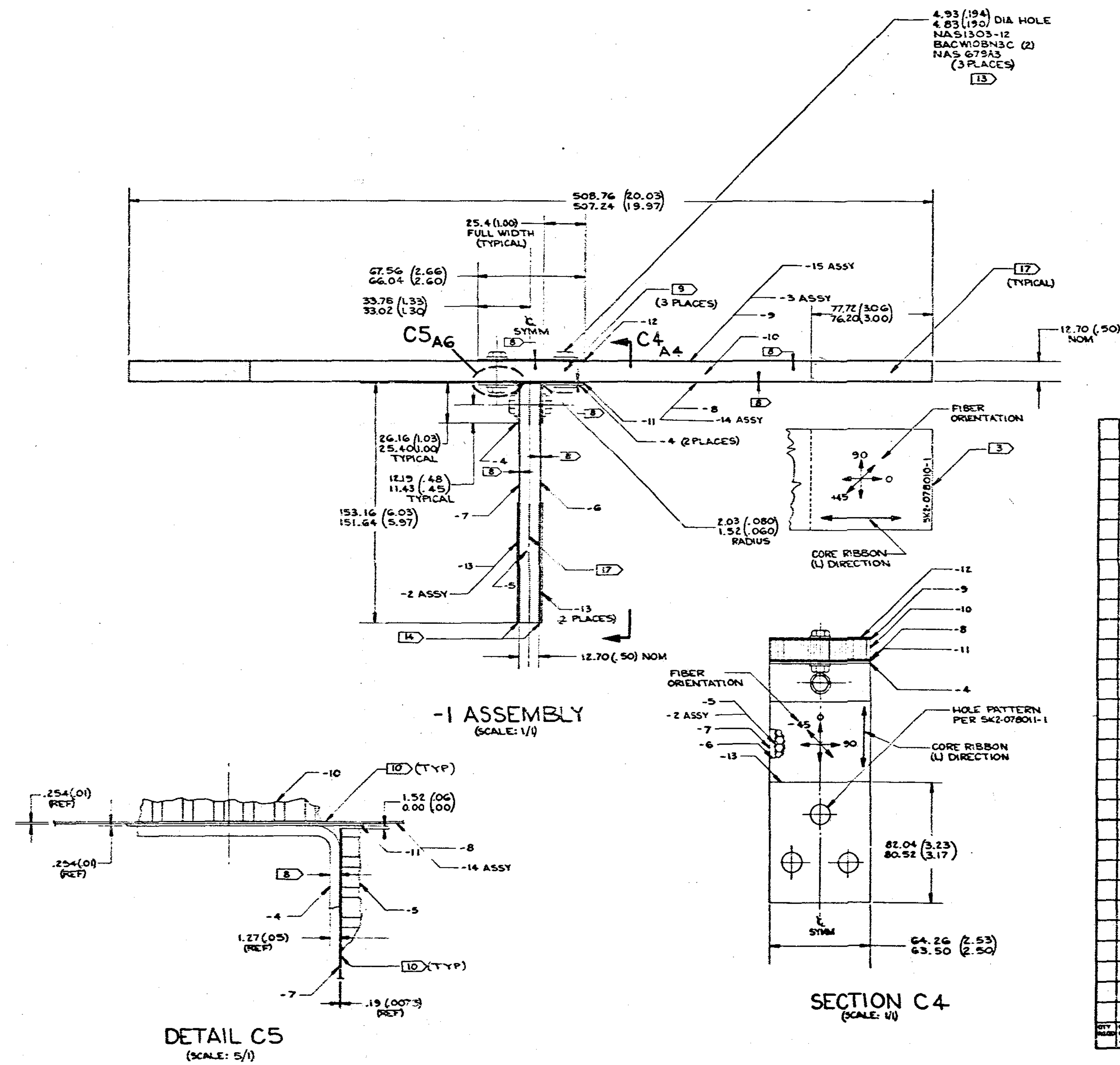
SIZE J CODE IDENT NO 81205 SK2-038107

SCALE NOTED

ORIG DWG BY IORG 2-3G14

SK2-038107

Figure 2-29



NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE)
   - FORM, STRAIGHTEN & FIT METAL PARTS PER BAC 5300
   - BOLT & NUT INSTALLATION PER BAC 5009
   - RIVET INSTALLATION & SYMBOLS PER BAC 5004
   - PART MARKING PER BAC 5307
   - FINISH CODES PER DOCUMENT D2-5000

2. XX.XXX MILLIMETERS (XX.XX INCHES) TOLERANCE ON ANGLES: ±1°

3. PART MARK USING FELT TIP PEN AT LOCATION INDICATED.

4. FABRICATION OF SPECIMEN SHALL BE CONTROLLED BY DOCUMENT D180-20545-5A, "PROCESS SPECIFICATION FOR PMR-15/GRAPHITE PREPRES". DOCUMENT ALL FABRICATION DEVIATIONS FROM THIS PROCESS SPECIFICATION.

5. INSPECT PRECURED LAMINATES AND PRECURED LAMINATE-TO-HONEYCOMB BONDED JOINTS PER DOCUMENT D180-20545-6, "NDI TESTING PROCEDURES FOR GRAPHITE/PMR-15 POLYIMIDE STRUCTURAL ELEMENTS".

7. IDENTIFY AND DOCUMENT VOIDS, DISBONDS, AND OTHER ANOMOLIES.

8. RECORD NOMINAL LAMINATE THICKNESSES, AFTER POSTCURE, AT LOCATIONS INDICATED.

9. BMS 8-126 TYPE 1, POLYIMIDE STRUCTURAL FOAM. INSTALL FOAM TO FULL DEPTH OF CORE, OVER THE AREA DESIGNATED, PRIOR TO ASSEMBLY OF CORE AND FACE SKINS. CURE AND POSTCURE FOAM PER BMS 8-126.

10. A7F-BLENDED AND PROCESSED PER D180-20545-5A; EXCEPT ADD 1% (BASED ON RESIN SOLIDS) CAB-O-SIL. TITANIUM-TO-TITANIUM LAP SHEAR STRENGTH SHALL BE A MINIMUM OF 1500 psi, WHEN TESTED PER BSS 7202, TYPE V. THE TEST PANEL SHALL BE ASSEMBLED AND TESTED PRIOR TO BONDING THE COVER ASSY.

11. HRH-327-3/16-4 (64.1 kg/m^3 (4 lb/ft^3)) FIBERGLASS/POLYIMIDE, HEXCEL PRODUCTS INC.

12. CLEAN PER BAC 5514.

13. TIGHTEN NUTS WITHIN TORQUE RANGE OF 18 TO 20 INCH POUNDS.

14. BMS 5-51, TYPE 2, GRADE 10 or BMS 5-101, TYPE 2, GRADE 10. BOND IN ACCORDANCE WITH BAC 5514. ITEM -13 TO ASSY. OF -5, -6 & -7

15. CELION 3000 (NR 150B2G FINISH)/PMR-15 PREPREG PER D180-20545-4A.

16. STRIP PER BAC 5771, APPLY DRY FILM LUBRICANT PER BAC 5811, TYPE VIII, CLASS I.

17. FINAL ASSEMBLY OPERATION: REMOVE CORE OVER THE AREA DESIGNATED AND POT WITH BMS 5-28 TYPE 5 OR TYPE 6.

18. THE PLIES ARE LISTED IN SEQUENCE, SET OFF BY PARENTHESIS STARTING FROM THE SIDE INDICATED BY THE CODE/PART NUMBER ARROW, e.g.:
   (0/90/±45)
   0
   90
   +45
   -45

PARTS LIST

QTY REQD	QTY REQD -15	QTY REQD -14	QTY REQD -3	QTY REQD -2	QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT NO	REV LTR
			AR	AR			BMS 8-126	POTTING		9					
					AR		BMS 5-28	POTTING		17					
			AR	AR			A7F	ADHESIVE		10					
				AR			BMS 5-51	ADHESIVE		14					
					6		BACW10BN3C	WASHER		12					
					3		NAS679A3	NUT		16					
					3		NAS1303-12	BOLT		16					
	-		1				-15	SKIN ASSY		CO-CURE -9 & -12 4 5 8					
		-	1				-14	SKIN ASSY		CO-CURE -8 & -11 4 5 8					
				2			-13	DOUBLER		.040 × 2.55 × 3.25 2024-T4 ALUM SHEET 12					
	1						-12	REINFORCEMENT		.010 (REF) (0, 90, ±45) LAYUP 15 18					
		1					-11	REINFORCEMENT		.010 (REF) (0, 90, ±45) LAYUP 15 18					
			1				-10	CORE		.50 × 2.55 × 20.03 11					
	1						-9	SKIN		.010 REF (±45, 90, 0) LAYUP 15 18					
		1					-8	SKIN		.010 REF (±45, 90, 0) LAYUP 15 18					
				1			-7	SKIN		.0075 (REF) (0, ±45) LAYUP 3 15 18 8					
				1			-6	SKIN		.0075 (REF) (0, ±45) LAYUP 15 18 8 3					
				1			-5	CORE		.50 × 2.50 × 6.00 11					
					2		-4	ANGLE CLIP		.050 REF (0, ±45, 90)s LAYUP 15 18 3 5					
			-		1		-3	COVER ASSY		4 5					
				-	1		-2	WEB ASSY		4 5					
					-		-1	SPECIMEN, TYPE 4, BOLTED ASSY		4 7				3	

CONTRACT NUMBER NAS1-15644

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON

SPECIMEN, TYPE 4, BOLTED-Gr/PI COMPOSITE JOINT, FINAL CONCEPT, TASK 1.4

J 81205 SK2-038108

TEST ONLY

APPLICATION

FASTENER CODES

SK2-038108

Figure 2-30

SECTION 3.0
CONCLUDING REMARKS

During this reporting period the principal program activities dealt with design allowables, small specimens and static discriminator tests.

Results of testing discussed in this report have led to the following conclusions.

- o Interleaved doublers is an acceptable design fix for Type 1 bonded and bolted joints.
- o Type 3 bolted joint design is adequate for the design load.
- o Cocured Type 3 bonded joints are currently beyond the "state-of-the-art" in processing of graphite polyimide to titanium for the required load level of 2.10 kN/mm (12 kips/inch).
- o Type 4 bonded and bolted joint designs are adequate for the design loads.

Specimen fabrication and testing to date has demonstrated that graphite polyimide composite can be joined by bonding or bolting and be made to transfer loads commensurate with the magnitude of loads expected for aerospace vehicles. Although some of the joints tested did fail in the joint area and not outside the joint area as had been the design requirements, the magnitudes of the loads actually transferred were substantial indicating viable joints can be designed and manufactured.

REFERENCES

1. J. L. Arnquist, and D. E. Skoumal, "Design, Fabrication and Test of Graphite/Polyimide Joints and Attachments for Advanced Aerospace Vehicles," Quarterly Progress Report #3, Contract NAS1-15644, NASA CR-159110, October 15, 1979.

2. Joyanto K. Sen, Robert M. Jones, "Stresses for Double-Lap Joints Bonded With a Viscoeleastic Adhesive: Part I, Theory and Experimental Corroboration", AIAA Journal, Vol. 18, No. 10, October 1980.

3. Joyanto K. Sen, Robert M. Jones, "Stresses In Double-Lap Joints Bonded With a Viscoelastic Adhesive: Part II, Parametric Study and Joint Design," AIAA Journal, Vol. 18, No. 11, November 1980.

4. Malcolm D. Campbell, Douglas D. Burleigh, "Thermophysical Properties Data On Graphite/Polyimide Composite Materials," NASA CR-159164, 1979.

5. Ronald K. Clark, W. Barry Lisagor, "Effect of Method of Loading and Specimen Configuration on Compressive Strength of Graphite/Epoxy Composite Materials," NASA Technical Memorandum 81796 dated April 1980.